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Geology and Hydrology of the Martinsburg Formation in Dauphin County, Pennsylvania

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BULLETIN W 24

Geology and Hydrology of the Martinsburg Formation in Dauphin County, Pennsylvania

by Louis D. Carswell and Jerrald R. Hollowell
Geologists, U.S. Geological Survey
with a section on geology

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Prepared by the United States Geological Survey, Ground Water Branch, in cooperation with the Pennsylvania Geological Survey

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PREFACE

Dauphin County south of Blue Mountain is an area of rapidly expanding suburban communities. Municipal water supplies and sewage disposal are lacking throughout most of the area. Water now used comes largely from drilled wells and sewage is disposed of in septic systems. Because more homes, schools, and commercial concerns are being built more and more water is sought. This report was written to provide information for those seeking water. The report provides information on the location, availability and quality of water that may be obtained for homes, public buildings, industries and agriculture.

The report contains detailed information on the rocks that underlie the Dauphin County area and the water contained in these rocks. The rock of the area is mostly shale, sandstone, and siltstone and is referred to collectively as the Martinsburg Formation. The rocks have been extensively fractured at one or more times in the geologic past.

Ground water in the Martinsburg Formation of Dauphin County occurs primarily in the fractures of the rocks. Detailed charts and diagrams are presented showing the specific capacities of tested wells, the depths at which wells yield water and the chemical character of the water, including contaminants.

This report will be of use to persons wishing to obtain ground-water supplies in the area. It will be helpful in locating wells to obtain their highest possible yields and in determining at what depth water may be obtained. Those wishing to increase the yield of their wells can use the techniques of well development discussed in the report.

The authors conclude that ground water can be obtained from wells in small to moderate quantities throughout the area investigated, but wells in valleys were found to have the highest yields. The ground water is free of contamination except in areas underlain by limestone or in local areas of concentrated housing.

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The Geology and Hydrology of the Martinsburg Shale in Dauphin County, Pennsylvania

by

Louis D. Carswell, Jerrald R. Hollowell
and Lucian B. Platt

ABSTRACT

The Martinsburg Formation in Dauphin County consists of shale, siltstone, sandstone, conglomerate, limestone, chert, and cherty mudstone. Three informal members of the Martinsburg are recognized, all dominantly shale. These members are characterized as follows: member A, the oldest, by the presence of limestone; member B, by the presence of chert; and member C, the youngest, by the presence of graywacke.

The Martinsburg is structurally complex and contains numerous thrust faults and structural discontinuities, which are interpreted to be the result of gravity slides. Several periods of deformation have occurred.

The Martinsburg is bounded on the north by the overlying Tuscarora Formation and on the south by older Ordovician carbonate rocks, which lie in thrust contact upon the Martinsburg.

Ground water occurs in the Martinsburg in secondary openings along joints, faults, and cleavage and bedding planes. The secondary openings are well developed near the surface and become progressively tighter as the depth increases. Borehole-velocity measurements and drilling data indicate that the circulation of ground water is limited to the upper few hundred feet of strata.

Ground water is generally available in adequate quantities for domestic use throughout the area underlain by the Martinsburg in Dauphin County. Specific capacities of domestic wells averaged 0.15 gpm per ft dd (gallons per minute per foot of drawdown) and ranged from 0.01 to 1.5 gpm per ft dd. The specific capacities of wells drilled to obtain the maximum available yield averaged 1.0 gpm per ft dd and ranged from 0.02 to 7.0 gpm per ft dd. Few wells drilled to obtain the maximum amount of water available yielded more than 100 gpm (gallons per minute), and none yielded more than 200 gpm; the average yield of these wells was about 50 gpm.

Wells in valleys—particularly in small valleys in the uplands—have higher specific capacities than wells along valley slopes or on hilltops. Wells drilled in the limestone member of the Martinsburg produce the highest yields.

The water table in the Martinsburg follows topography. It is typically about 20 feet below land surface in the uplands and intersects the land surface in the valleys, where ground water is discharged. The water table fluctuates annually in response to recharge during the fall and winter months and discharge during the summer months—when large quantities of water are lost by evapotranspiration. Water-level fluctuations of small amplitude result from severe storms, earth tides, barometric changes, and severe earthquakes.

Development of two wells (drilled by air rotary methods) by surging with a solution of hexametaphosphate increased the specific capacity of the wells by 14 and 21 percent.

Urbanization in Dauphin County has changed the flow regimen of Paxton Creek. As a result, the base flow of Paxton Creek in 1963, was sustained 26,000 gpd (gallons per day) over normal.

Ground water in the Martinsburg Formation is of the calcium bicarbonate type. Contamination is restricted to local areas of concentrated housing and to areas underlain by limestone.

INTRODUCTION

PURPOSE AND SCOPE

The area underlain by the Martinsburg Formation in Dauphin County is rapidly changing from a largely agricultural area to a group of residential suburban communities. Because of the rapid suburban growth and lack of municipal water supply and sewage disposal facilities throughout much of the area, an understanding of the relationships between the stratigraphy, structure, and topography of the area and the occurrence and quality of ground water was considered highly desirable, by both the Pennsylvania Topographic and Geologic Survey and the U.S. Geological Survey. This report is the product of the investigation conducted by the two organizations to develop an understanding of those relationships.

Detailed geologic mapping of the Harrisburg East 7½-minute quadrangle and parts of adjoining quadrangles was the responsibility of Lucian B. Platt who was supported in this project by the Pennsylvania Geological Survey as a part of a long-range plan of providing geologic maps of the entire State.

LOCATION AND EXTENT OF THE AREA

The Martinsburg Formation crops out in a northeast-trending belt in central Dauphin County and forms the northern part of the Great Valley section of the Valley and Ridge physiographic province. The area underlain by the Martinsburg is approximately 8 miles wide and 14 miles long. The Martinsburg is bounded on the north by the disconformably overlying Juniata Formation and the Tuscarora Formation, and on the south by a series of overlapping fault sheets of generally older carbonate rocks apparently thrust onto the Martinsburg.

The area covered by this report is somewhat smaller than the entire area underlain by the Martinsburg in Dauphin County. (See Fig. 1.) The investigation has been restricted to that part of the area for which modern 7½-minute quadrangle maps were available and therefore does not include the small area underlain by the Martinsburg in the Steelton and Middletown 7½-minute quadrangles (See Explanation on Plate 1).

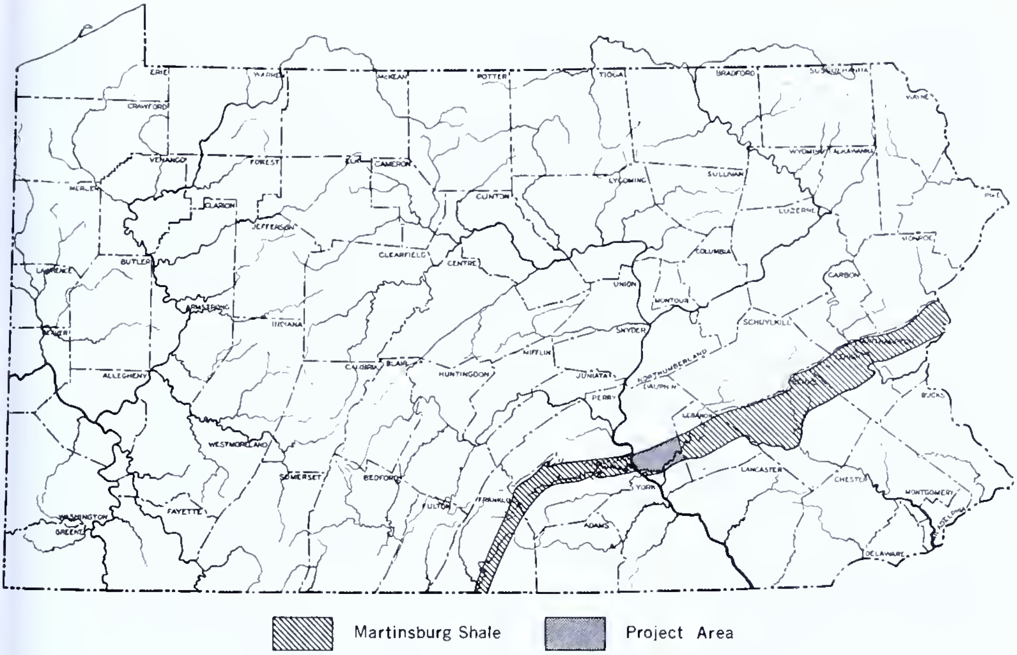

Figure 1. Map of Pennsylvania showing area underlain by the Martinsburg Formation and the location of the project area.

PREVIOUS INVESTIGATIONS

Previous geologic work in the Martinsburg Formation area of Dauphin County consists of the reconnaissance mapping (on a scale of 1:126,720) of the Second Pennsylvania Geological Survey (Lesley, 1891), a description of the locations of some of the limestone units (Miller, 1937), brief discussions of the rock types in the area in numerous guide books and journal articles, and the interpretation that much of the Martinsburg in the area represents a klippe of Taconic* age (Stose, 1946).

Previous hydrologic information on the area is restricted to a reconnaissance report on the ground water in southeastern Pennsylvania (Hall, 1934).

METHODS USED IN THIS INVESTIGATION

Geologic mapping of the Martinsburg Formation in the Harrisburg East 7½-minute quadrangle (Plate 1) and the immediately adjacent areas was done by Lucian B. Platt, who is also primarily responsible for the discussion of the geology of the area.

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* The term "Taconic" is not used by the U.S. Geological Survey.

Geologic mapping of the Martinsburg Formation in parts of the Hummelstown, Harrisburg West, Manada Gap, and Enders 7½-minute quadrangles (Plate 1) and the collecting of the hydrologic data throughout the area were done by L. D. Carswell and J. R. Hollowell who are also responsible for the hydrologic interpretations in this report.

The hydrologic investigations included the gathering of records on 400 wells in the Martinsburg. Approximately 280 representative wells are shown on Plate 1 and listed in Table 2. Information concerning the wells was obtained mostly from well-drillers' records, and six test wells were drilled to aid in determining hydrologic characteristics of the formation.

Continuous water-level measurements were made on 12 wells for various periods of time according to the availability of the wells. A recording barometer was operated at the location of three of the test wells in Lower Paxton Township from July to October 1962, and a continuous recording rain gage was operated nearby during the summer and fall of 1963. Because of the availability of stream records for Paxton Creek for the period from 1940 to 1950, a temporary gage was installed and operated by the authors at the site of the previous gaging station. Discharge measurements were made at the gaging station by the Surface Water Branch of the U.S. Geological Survey from April 1963 to June 1964.

Pumping tests were made on 12 wells for periods ranging from 1 to 3 hours. Observation wells were available for only four of these tests. Measurements of the velocity of the water moving up the borehole were made, in most of the wells tested, by injecting slugs of brine at known depths and tracing their movement with a fluid-conductivity probe. Electric, gamma ray, caliper, and fluid-conductivity logs were made of 8 wells.

Well development was studied in two wells by surging the wells with chemical well-cleaning additives.

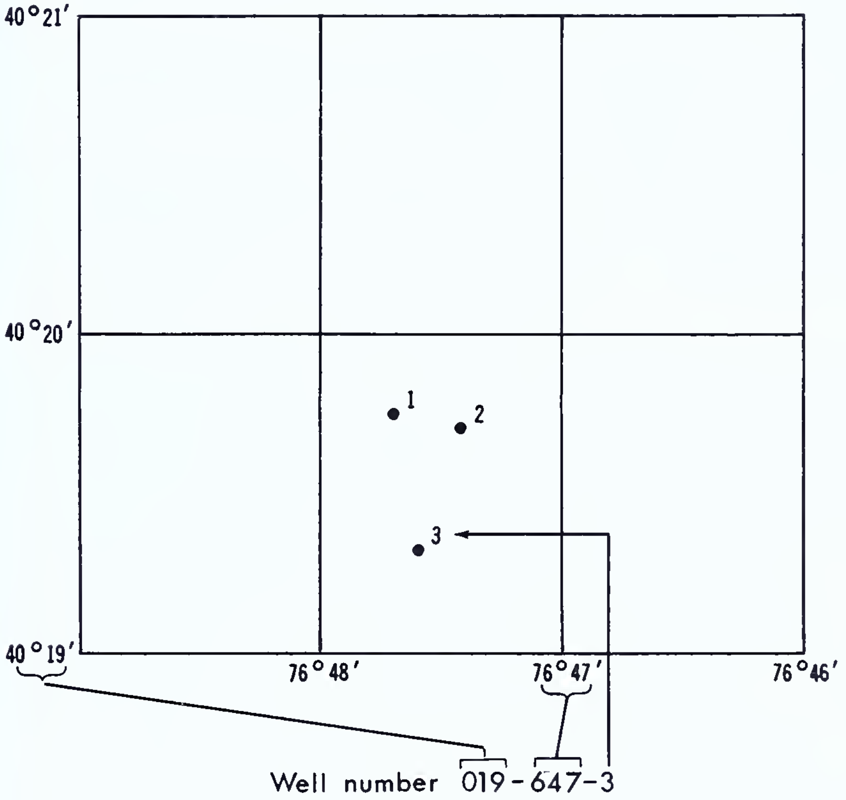
Water samples for chemical analysis were collected from the known large-yielding wells in the area and from several different depths in the test wells. In addition, samples were collected specifically for determination of ABS (Alkyl benzene sulfonate) content, a significant constituent of present-day household detergents. Chemical analyses of the water were made by the Quality of Water Branch, U.S. Geological Survey and are given in Table 3.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report shows the location of wells according to a latitude and longitude location system illustrated in Figure 2. The latitude and longitude system consists of a statewide grid of 1-minute parallels of latitude and 1-minute meridians of longitude. The wells in a 1-minute quadrangle are numbered consecutively in the order inventoried. The well number is a composite of three groups of numbers separated by hyphens: the first group is composed of the last digit of the degree and the two digits of the minutes that define the latitude on the south side of a 1-minute quadrangle; the second group is composed of the last digit of the degree and the two digits of the minutes that define the longitude on the east side of a 1-minute quadrangle; and the third is the number assigned consecutively to the well in the quadrangle.

ACKNOWLEDGMENTS

The cooperation, information, and access to private property provided by individual land owners and companies are gratefully acknowledged.



Well number 019-647-3 was the third well inventoried in the 1-minute quadrangle north of the 40°19′ parallel of latitude and west of the 76°47′ meridian of longitude

Figure 2. Sketch showing the well-numbering system used in this report.

The authors express appreciation for cooperation and assistance provided by the following well drillers: C. H. Eichelberger, Edwin Gerlach and Sons, Inc., and especially Earl Kohl and his staff of Kohl Bros., Harrisburg, with whom problems of water supply in the Martinsburg were discussed frequently. The well-organized records of well data and pumping tests maintained by Kohl Bros., during the past 25 years operation of the company, greatly facilitated the gathering of hydrologic data for this report.

Stimulation and assistance provided by discussing the problems of geology and hydrology of the Martinsburg with many members of the U.S Geological Survey and the Pennsylvania Geological Survey are gratefully acknowledged. The following individuals are singled out for their particular contributions: David B. MacLachlan, of the Pennsylvania Geological Survey, provided information on the contact of the Martinsburg with the older carbonate rocks south of the project area; John Riva, of Villanova University, identified the meager fauna collected; F. M. Swartz provided regional information on the Martinsburg and its equivalents; and S. S Oriel, of the U.S. Geological Survey, reviewed the section on geology and provided many helpful suggestions.

William C. Roth of the U.S. Geological Survey, assisted in the pumping tests, measured water levels, and made borehole-velocity measurement and electric logs.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The area underlain by the Martinsburg Formation in Dauphin County is generally a well-dissected, gently rolling upland. Swatara Creek flow through the southeast corner of the area covered by this report and—with the tributaries of Beaver, Manada, and Bow Creeks—drains the eastern half of the area. The Susquehanna River drains the western part of th project area both directly and by minor tributaries, including Paxton Creek north of Harrisburg and Spring Creek south of Harrisburg.

Topographic relief on the Martinsburg in the area is over 700 feet ranging from an altitude of less than 300 feet in the Susquehanna Rive valley at Harrisburg to an altitude of more than 1,000 feet on Blue Mountain, in the northeast part of the area.

In general, the topographic relief on the area underlain by the Martinsburg is a reflection of the bedrock lithology. Hills are underlain by sandy o cherty rock; and valleys, swales, and gullies are developed on limestone o shale. The generally eastward to northeastward or westward to southwestward flowing streams and valleys are stratigraphically controlled, whereas the generally southward flowing streams are structurally controlled by joints and faults in the bedrock.

CLIMATE

The climate of Dauphin County south of Blue Mountain is moist and temperate, having an average annual precipitation of 43 inches and an average temperature of 53°F. The average frost-free period is 201 days, beginning April 10 and ending October 28. The average monthly precipitation and temperature for the Harrisburg vicinity are given in the following table.

Month	Average Monhtly precipitation (in inches)	Average Monthly temperature (in °F)
January	3.08	31.8
February	2.60	32.6
March	3.77	40.3
April	3.64	51.8
May	4.37	62.7
June	3.93	71.3
July	3.94	75.7
August	4.27	72.4
September	3.24	66.4
October	3.37	55.7
November	3.38	43.9
December	3.25	33.5

CULTURE

The population within the area of this investigation in 1960 was 126,522. In Harrisburg and the adjacent boroughs of Penbrook and Paxtang the population decreased 9,808 during the preceding decade to 85,284 in 1960, while in the adjacent townships of Susquehanna and Lower Paxton the population increased 17,465 to 35,092.

The major industries within the area of investigation are located in the vicinity of Harrisburg and along US Route 22. They include food and kindred products, primary metal, apparel and other textile products, fabricated metal, printing and publishing, machinery and equipment, and stone and clay products. Outside Harrisburg and the suburbs, the area underlain by the Martinsburg Formation is farmed extensively. The climate favors production of livestock, poultry, dairy, field crops, and fruit crops.

WATER USE

The city of Harrisburg obtains its municipal water supply from a surface reservoir in Clark Creek Valley, about 13 miles northeast of the city limits. The Dauphin Consolidated Water Company, which supplies water to many of the suburbs of Harrisburg, obtains water from Beaver Creek, from a limestone quarry in southeastern Harrisburg, and from a surface reservoir near Dauphin, Pa. In addition, the Hershey Water Company, which serves a part of the area underlain by the Martinsburg Formation just north of Hershey, obtains water from Manada and Swatara Creeks. Drilled wells in the Martinsburg are used by only a few small private water companies serving housing developments and by local distribution systems operated by the Dauphin Consolidated Water Company. Thus, all of the water distributed by the municipality and some of the water distributed by the Dauphin Consolidated Water Company is obtained from surface reservoirs outside the area of this investigation, and almost all of the water distributed is obtained from surface reservoirs.

Figure 3 shows the approximate area served by the municipal water system, the Dauphin Consolidated Water Company, and the Hershey Water

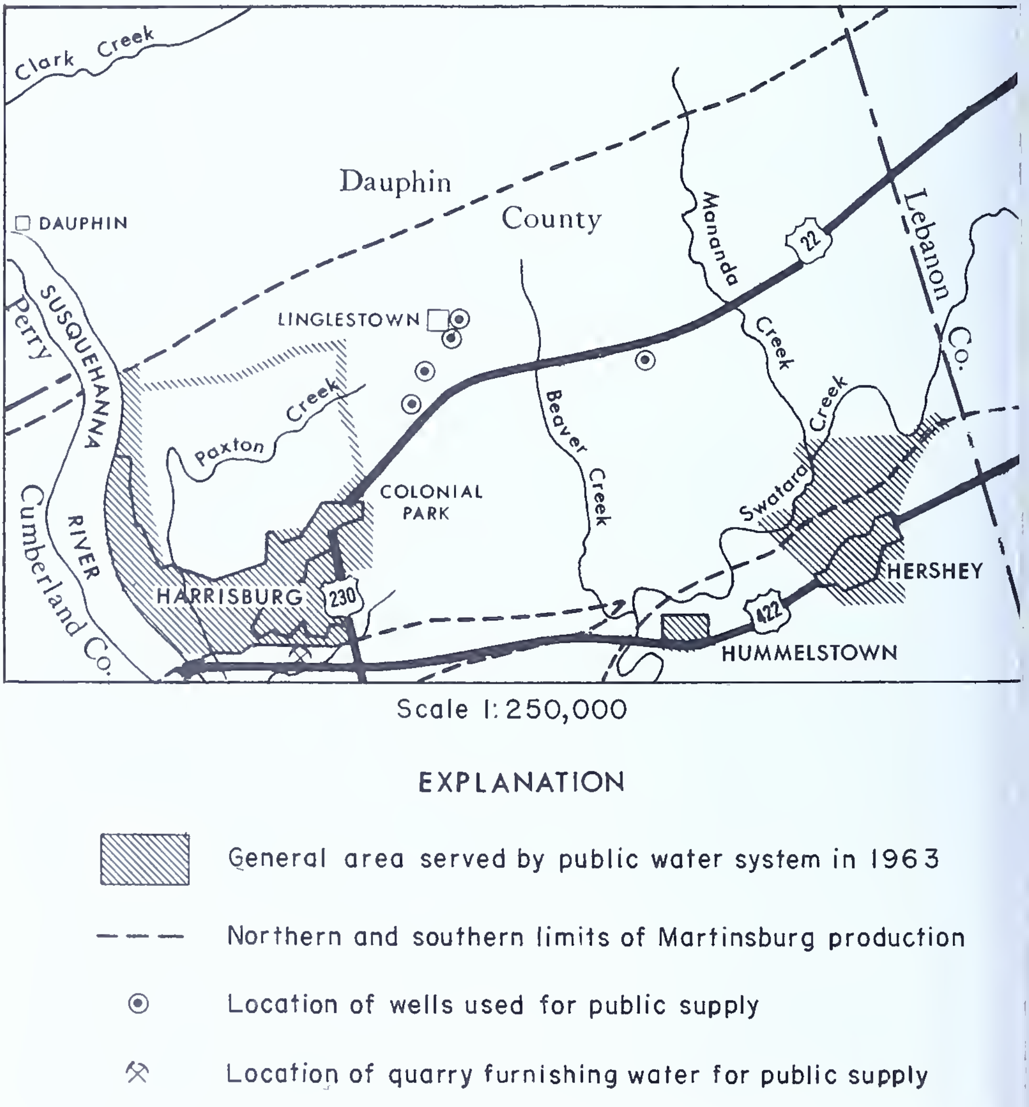


Figure 3. Map showing areas served by public water systems.

Company, and it shows the location of public-supply wells. Information on the use of water from wells owned or operated by these supply-distribution systems is shown on the following table.

Water Company	Well number	Number customers	Average use (thousand gallons per day)
Operated by Dauphin Consolidated Water Co.	018-648-1	3	3
Do.	019-647-1	30	30
Elmer T. Bolla Water Co.	020-643-2	16	3
Linglestown Water Co.	020-646-5	130	35
Do.	-6	130	35
St. Thomas Water Co.	020-646-7	60	28

Water supply for the rest of the area, which is not served by central distribution systems, is almost entirely from drilled wells and is predominately for domestic purposes.

GEOLOGY

By Lucian B. Platt

GENERAL

The Martinsburg Formation in Pennsylvania is mostly medium- to dark-gray shale and contains interbeds of siltstone and sandstone. Its lower contact with Middle Ordovician carbonate rocks is regionally gradational but locally unconformable (Geyer and others, 1958). The Martinsburg is overlain by Upper Ordovician and Silurian coarse detrital rocks. From the Susquehanna River westward the upper contact is conformable, but east of Dauphin County the Silurian Tuscarora Formation is believed to lie unconformably on the Martinsburg (Stose, 1930). In the Harrisburg area these contacts are not well exposed, for thrust plates of the older carbonate sequence extend onto the south edge of the Martinsburg, and colluvium covers the contact with the younger coarse detrital rocks.

Within the belt of Martinsburg Formation between the Susquehanna River and Hamburg, Pa., about 60 miles to the east, previous workers found rock types not known within the Martinsburg farther east or west. Miller (1937) and Moseley (1952) found thin-bedded, shaly limestone within the Martinsburg, but never found fossils associated with them. Stose (1946) noted red shale and chert within this part of the Martinsburg belt and recorded graptolites that seemed to date the enclosing rock as

Early and early Middle Ordovician, too old for the recognized late Middle and Late Ordovician age of the Martinsburg.

Kay (1941) and Stose (1946) inferred that one or more rock types found in the belt of Ordovician (Martinsburg) shale in Pennsylvania might be allochthonous. Stose concluded that a large plate of shaly rocks was thrust onto the Martinsburg Formation approximately in the area between the Susquehanna River and Hamburg, Pa. His so-called "Hamburg Klippe" included all the shale within these boundaries. His interpretation was based on the clearly atypical rock types found in this area, the apparently anomalously old fossils, and a vague correlation with units known from the "Taconic Klippe" in eastern New York. Because no detailed maps of the problem area were published, stratigraphic and structural questions have remained largely unanswered, although extensive Ordovician deformation have been recognized throughout southeastern Pennsylvania (see Behre, 1926; Bricker, 1960; Drake and others, 1960; Maxwell, 1962; B. L. Miller, 1926).

The present authors have been able to map several rock types within the belt of the Martinsburg, although each is discontinuous. Three informal members have been identified, two of which are inferred to have slid by gravity into the third at the time of deposition of that third member. This interpretation is presented while recognizing that it is based on mapping within only a small area. The interpretation accounts for the local observations and is not known to be contradicted by evidence from elsewhere in the belt of the Martinsburg Formation.

The age limits of the shale have been difficult to define rigorously (Swartz, 1948), because fossils are scarce and the relation of Martinsburg graptolites to the better known shelly fauna is imprecisely known.

STRATIGRAPHY

The bulk of the Martinsburg Formation is dark-gray shale or shaly siltstone that weathers olive to brown. Minor amounts of red, maroon, and purple shale, red and olive siliceous shale or chert, aphanitic dark-gray limestone and limestone edgewise conglomerate, sandstone of rounded quartz grains, clayey dolomite, and poorly sorted graywacke—including pieces of many of these minor rock types—have been found. They are grouped into three informal members, in order of decreasing age, as follows: member A, characterized by the presence of limestone; member B, characterized by the presence of chert; and member C, characterized by the presence of graywacke.

Member A

Member A is about 400 feet thick and is characterized by limestone interbedded with shale and lenses of edgewise conglomerate composed of limestone pebbles in claystone or in quartz sand matrix. The limestone beds are between one-fourth inch and 2 inches thick, aphanitic, and dark-gray, becoming light bluish-gray on a weathered surface. Some dolomitic beds are also present and range from medium-gray on a fresh surface to light bluish-gray or tan on a weathered surface. The carbonates are interbedded with dark-gray shale, laminated with siltstone layers in some places. The conglomerate contains pebbles of limestone as well as dark-gray calcareous siltstone. A striking feature of the conglomerate is the very well rounded sand grains in the matrix. In two places sandstone has been found as float unaccompanied by limestone pebbles. The member is relatively well exposed south of Paxton Creek along the road to Glenwood, especially in roadcuts at about 400 feet above sea level.

A faunule of graptolites was recovered from silty interbeds in medium-gray dolomite near the western edge of the Harrisburg-East quadrangle in the main belt of this member. The abundance of *Dictyonema* and the lack of any other forms suggest an Early Ordovician age to John Riva (personal communication). This is older than any rocks generally considered to be Martinsburg Formation.

In all localities where exposures of strata presently beneath member A have been studied, the underlying rock resembles other members of the Martinsburg. Where stratigraphic relations have been established, the lower contact of member A is faulted. Several bands of this unit end abruptly along strike against member C without apparent stratigraphic thinning.

The upper contact of this member had not been seen in detail, as this member occupies valleys where adjacent rocks have slumped down over the contact. However, mapping indicates that the overlying strata are conformable with member A, and that the change in lithology takes place within a few tens of feet of shale. Where this shale is gray it has been included in member A because of sparse interbedded plates of carbonate, but where the shale is variegated or red it is included in member B.

The contrast between member A and locally exposed units believed to be correlative is marked. This member is black and clay-rich; the Lower Ordovician Stonehenge and Rickenbach Formations in Lebanon County are dominantly thick-bedded crystalline carbonates with only rare thin shale laminae (Geyer and others, 1958). However, limestone edgewise conglomerate is in both member A and the Stonehenge Formation.

Member B

Member B contains interbedded red, maroon, purple, and gray shale and mudstone, locally white-weathering shale, siliceous shale, and chert. The chert or siliceous shale is mainly red in the northern part of its outcrop area and dark olive in the southern part. Although red and variegated shale are prominent in this member, neither is reliable for tracing a bed or for identifying the unit. In plowed fields the red beds can be seen to end and begin abruptly, generally within a distance equal to five to ten times their thickness. Red beds also have been found in member C.

The cherty beds crop out better than the other rocks of the Martinsburg Formation in the Harrisburg area, although they are ordinarily 20 feet thick or less. Manganese staining is associated with the cherty beds, especially immediately beneath them stratigraphically. Shale adjacent to the stained beds is commonly bleached to light tan and contains fragments of graptolites in several places. The bleached shale is believed diagnostic of this member.

Member B appears to be conformable upon the underlying member, although fossil evidence suggests that a considerable part of the Lower Ordovician may not be represented. Member B yielded graptolites at several localities (Plate 1). The graptolite fragments include such characteristic forms of Normanskill or older age as *Climacograptus scharenbergi* and *C. parvus* (John Riva, personal communication). Thus member B also seems too old for inclusion in the Martinsburg.

Distinguishing member B from member C of the Martinsburg is difficult, for both have red, variegated, and even some green beds. A prominent exposure 1 mile northwest of Colonial Park, along a road that trends northwestward and then northward, about 1,800 feet southeast of Paxton Creek, illustrates the problem. This outcrop, if considered by itself, shows no feature characteristic of either member B or member C in this area. However, as its westerly continuation is discordant with a thrust plate of member A and member B, it is interpreted as being in member C.

The best criterion for mapping member B in the northern part of the Harrisburg-East quadrangle is continuity of the cherty beds. In the southern part of the quadrangle, no unique criterion for identifying member B is evident. The thickness is estimated as about 1,000 feet.

Member B contrasts sharply with correlative units cropping out in nearby counties. For example, Geyer and others (1958) described the Middle Ordovician Annville Limestone, Myerstown Limestone, and the Hershey Limestone of Lebanon County to the east, and Craig (1949) describes the similarly limy Mercersburg and Oranda (Cooper and Cooper, 1946) Formations* in Cumberland and Franklin Counties to the southwest. These limestone units are not like shaly and cherty member B.

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* The names Mercersburg and Oranda Formations are not adopted by the U.S. Geological Survey.

Member C

Member C is dominantly dark-gray shale and poorly sorted siltstone and sandstone. Interbeds of graywacke conglomerate are common. The member weathers olive or olive brown, ultimately becoming light brown or tan. Good outcrops of these rocks can be found in the vicinity of the H-shaped intersection crossing Paxton Creek 2 miles north of Glenwood and along U.S. Route 22 in the eastern part of the Harrisburg-East quadrangle. Reddish mudstone interbedded in this member can be seen 1½ miles southwest of Linglestown along the road that follows Paxton Creek.

Although the flakes of shale and bits of various rock types within the beds of graywacke conglomerate are mainly less than 1 inch in longest dimension, a few roadcuts display larger included exotic blocks. Because roadcuts are small, blocks more than 3 feet long have not been seen. Blocks tens of feet long are believed to be present. This belief is based on the lack of continuity of some chert outcrops from north Progress Avenue west to the State Hospital in Harrisburg. Float of graywacke conglomerate containing chert pebbles is on strike with each of these chert outcrops, which seem stratigraphically anomalous.

The graywacke conglomerate includes dark, aphanitic limestone containing shale, silty limestone, calcarenite, red, black, olive, and (rarely) green chert, and gray, red and green shale. Many of the pebbles and blocks appear to be from members A and B, although no detailed petrographic work has been done. Most carbonate pebbles have been dissolved to leave only holes. These pebbles and larger blocks obviously reflect the rock types in the source area—rock types which, it must be noted, are not known to crop out in Pennsylvania except in the Martinsburg belt. McBride (1962) showed that graywacke in the Martinsburg Formation in the entire belt from West Virginia to New York had a source area to the south and southeast; hence, the pebbles and larger pieces also came from that general direction. In addition, no other source area seems possible, for rocks in other directions provide neither such source rocks nor gaps in the stratigraphic section from which all such rocks could have been removed. The pebbles and larger blocks were deposited in member C during marine deposition of the shale and siltstone of this member.

The conglomerate described above, consisting of large blocks and small pieces of shale and other rocks in shale, is not the same as the Paxton Creek Conglomerate* of Willard and Cleaves (1938), which is composed of quartz pebbles. The stratigraphic position of the quartz-pebble conglomerate remains in doubt, as its one remaining outcrop is surrounded by pavement in the city of Harrisburg. It is arbitrarily included here in member C.

No fossils have been found in rock characteristic of member C, which, in the Harrisburg area, is estimated to be about 1,500 feet thick. Except for the graywacke conglomerate this member appears to be the equivalent of typical Martinsburg.

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*The name Paxton Creek Conglomerate is not adopted by the U.S. Geological Survey.

STRUCTURE

Bedding observed in deep, fresh roadcuts and in creek beds strikes north 70° to 90° east and dips steeply to the south. Because most exposures are deeply weathered, slumped, or show disturbed bedding, measurements made at the few satisfactory exposures are of little aid in mapping, even though these measurements indicate a uniform attitude of the bedding. Cross lamination, graded bedding, and other criteria show the rocks have a southward regional dip and are not overturned. No closed folds were identified by the geometry of dips.

Fracture cleavage is well developed in the southeastern part of the area; it strikes north 70° east, and it dips southeastward generally more steeply than bedding. In the southeastern part of Harrisburg-East quadrangle, kink bands dipping 10° to 20° south have been observed. These bend fracture cleavage as well as bedding, but otherwise the time of their formation is unknown.

Minor folds strike approximately east and plunge from less than one to several tens of degrees in either direction. Outcrops near one another may exhibit plunges that differ by 60°. The wide range of these plunges may be interpreted either as evidence of more than one period of deformation (for which there is considerable regional evidence), as evidence for hetergeneous deformation such as gravity sliding (for which there appears to be local evidence), or as evidence of both.

Strike-slip faults have been mapped extensively in Lebanon County by Moseley (1954) and Bricker (1960). In the Harrisburg area field relations permit the interpretation of such faults in several places, but only in one place does a fault seem required to satisfy the field evidence. In the northeastern part of the Harrisburg-East quadrangle a north-trending fault has been mapped as crossing a chert band and extending a short distance south along Beaver Creek. The displacement of the chert bed is about 100 feet. Structural discontinuities have also been drawn along several small valleys, but none shows clear strike-slip displacement.

Several thrust faults have been mapped on the basis of stratigraphic discontinuities and variation in the trend of traceable units on opposite sides of the discontinuities. Although the exact location of these thrust faults can rarely be determined accurately, the amount of displacement along the faults can be estimated from a consideration of the facies. Thus, the fine dark carbonates and shale of member A and the chert, variegated shale and mudstone of member B contrast sharply with carbonate sections of the same age exposed to the north (Fettke, 1948), to the south (Swartz, 1948), to the east (Willard, 1938), and to the west (Craig, 1949). The dominantly shaly rocks here designated member A and member B apparently have come from beyond the known carbonate section and have moved northward or northwestward several tens of miles. It is inferred that they moved by gravity sliding because of the geologically familiar argument that they are too thin to have transmitted the necessary push from the rear and because the individual plates are now disconnected not only from their source but also from each other in their present position embedded in member C.

GEOLOGIC HISTORY

In the Harrisburg area, the known geologic history begins with the formation of Lower Ordovician dark carbonates and shale, which probably were deposited at least 20 miles to the south or southeast. Fossils have not previously been reported from these rocks, although R. L. Miller (1937) discussed these strata, and Moseley (1952) examined them briefly. The limy rocks changed upward to siliceous shale and mudstone of member B which may be conformable with member A. The rocks of member B may be of Middle Ordovician age; they resemble and are perhaps contemporaneous with the Mount Merino Formation* of Ruedemann (1942) of New York State. Member B, like the underlying somewhat limy rocks and like its presumed correlative in New York and Vermont (Theokritoff, 1964), is believed to be allochthonous, having been deposited at least 20 miles to the south or southeast. Autochthonous rocks of Lower and Middle Ordovician age in the Harrisburg area are believed to be similar to the carbonate sequence exposed nearby to the south (Prouty, 1959). The thrust plate of carbonate rocks along the southern border of the Harrisburg-East quadrangle is not exactly similar to that sequence, however, suggesting that it may also have been transported several miles.

In Dauphin County the deposition of carbonate changed gradually to that of shale as deposition of member C of the Martinsburg Formation began. The bottom of this unit is not easy to define because of this gradual change. Southward, in the area of deposition of members A and B, shale deposition began much earlier.

Small-scale sedimentary features in the Martinsburg Formation have been studied by McBride (1962), who concluded that the graywacke was derived from the south. Flakes of black shale are found in the correlative Reedsville Formation to the north and northwest. Although they are less common than in the Martinsburg, they suggest a southerly source, as McBride observed. Coarse conglomerate, containing blocks similar in composition to members A and B, is present in the graywacke. These blocks, however large, were apparently laid down during and as a part of deposition of the Martinsburg (as it is usually described) in a marine environment. However, because the Martinsburg has been deformed at least once after deposition many details have not yet been worked out.

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* The name Mount Merino Formation is not adopted by the U.S. Geological Survey.

The belt of Martinsburg Formation now exposed was probably once covered by the Tuscarora Formation and younger rocks. Cleavage extensively developed in the Martinsburg, especially east and south of the Harrisburg area, was formed perhaps during some later part of the Paleozoic Era, but this cannot be proved in the Harrisburg area.

INTERPRETATION AND DISCUSSION

Noteworthy results of this study include fossil dating of members A and B and recognition in the Martinsburg Formation of conglomerate containing exotic blocks.

Member A (Early Ordovician) and member B (probably Middle Ordovician) are both older than the base of the Martinsburg as generally recognized and their facies is distinctively different from correlative rocks in the general vicinity. These two members are believed to be allochthonous. Kay (1941) inferred exactly this kind of relation from regional considerations, and Stose (1946) tried to formalize this idea with the evidence available to him. The structure recognized here, however, differs markedly from that envisaged by Stose. The time of movement of the allochthonous masses to their present sites is reasonably well indicated by the conglomerate of exotic blocks in member C of the Martinsburg. Similar relations have been reported from the Taconic area by Zen (1959) and Berry (1963).

Apparently, the so-called Taconic orogeny in the Harrisburg area consisted of large and small gravity slides of shaly rocks into an area of active deposition of shale. A structural discontinuity below the Bald Eagle* of Grabau (1909), Juniata, and Tuscarora Formations is, therefore, indicated—even if it cannot be shown locally that sedimentation stopped and erosion took place during the Late Ordovician.

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* The name Bald Eagle Formation is not adopted by the U.S. Geological Survey.

HYDROLOGY

GENERAL

The hydrologic cycle is the continuing circulation of water from the oceans (or other surface-water bodies) through the atmosphere to the land, from where it moves to bodies of surface water either by overland runoff or by infiltration and subsequent underground movement to points of discharge. Alternatively, the water may be returned to the atmosphere by evapotranspiration before it reaches a surface water body.

This report is concerned primarily with that part of the hydrologic cycle that relates to the movement of ground water along flow paths through the interconnected openings in the earth to points of discharge.

Hall (1934, p. 56-57) concluded that water in the Martinsburg was stored in and transmitted through an aquifer composed of openings along joints, faults, and bedding planes and that these openings decreased in size and number with depth. The decrease in the size and number of openings with depth decreases the ability of the aquifer at depth to store and transmit water. Not only do the openings forming the skeletal aquifer become fewer and tighter with depth, but they may be laterally discontinuous.

It was observed by Ellis (1906) that joints and other fractures are more open near the surface than they are at depth; however, there is little agreement as to the relative importance of processes that enlarge these openings in time so as to permit the circulation of ground water. In this report it is assumed that the solvent action of circulating ground water on the rock on either side of the joints and other fractures is largely responsible for enlarging these openings with time for the following reasons: (1) changes in the amount of total dissolved solids in water samples collected at progressively greater depths in wells in the upland or recharge area indicate continued solution of mineral matter below the water table; (2) in drilling wells in the Martinsburg, chips of weathered rock are returned to the surface wherever there is an increase in water yield indicating that rocks in the yielding zone have undergone chemical weathering; (3) electric logging and brine tracing of the drilled wells show the weathered zones to be major water-yielding zones.

The most promising topographic environment for the solvent action of circulating ground water is in the stream valleys in the uplands. The locations of most such valleys in the uplands are controlled by structural or stratigraphic features and only such valleys are considered here. The valleys presumably have permeable zones developed along the joints and other fractures. At any point along such a valley ground water may be visualized in plan view as discharging towards that point from three directions—along comparatively short flow paths from either hillside, and from upstream, parallel with the valley. In these upland valleys, increased secondary porosity and permeability along the structural features that control the location of the valley are to be expected. As this water has traveled along comparatively short flow paths, it probably has not reached chemical equilibrium with the bedrock environment and, therefore, is able to increase the size of the openings along the joints and other fractures by solvent action.

The development of secondary porosity and permeability progresses downstream from the headwaters and increases as the volume of water transmitted by underflow increases, thereby providing large quantities of water to enlarge the joints and other fractures.

The most favorable topographic environment for the solvent action of circulating ground water should also be the most favorable location for obtaining high-yielding wells in the Martinsburg Formation. The following table shows that wells in valleys do have higher yields per foot of saturated sediments than have wells in other environments.

Topographical setting	Hill top	Upper hill slope	Lower hill slope	Valley
Number of samples	41	21	7	11
Well yield per foot of saturated rock	.12	.16	.23	.28

The valley of the master stream, such as the Susquehanna River, is generally an unfavorable location for obtaining high yields from wells in the Martinsburg. There are two reasons for this: first, the water discharging upward into the valley has usually traveled the longest and most circuitous flow path along the ground-water flow system and has, in many instances, reached chemical equilibrium with the bedrock environment. Thus, it has comparatively little ability to increase the openings along joints and other fractures by solvent action, and chemical redeposition along openings may plug or partially plug existing openings. The second reason is the low gradient of the master stream valley, which reduces markedly the amount of water being transmitted downstream through the poorly permeable bedrock beneath the stream.

OCCURRENCE OF GROUND WATER

Ground water in the Martinsburg Formation in Dauphin County occurs chiefly in secondary openings in the rock, such as joints and other fractures. Primary openings (the void spaces between the individual grains of a rock) have been obliterated in the Martinsburg by compaction and cementation following deposition. Steep-dipping joints and other fractures are the most important secondary openings through which ground water can flow in the Martinsburg.

Data concerning the distribution in depth of the openings along joints and other fractures has been derived indirectly during this investigation and consists of two separate lines of evidence. The first is from information provided by the local well drillers who have recorded the depths at which water-bearing fractures were penetrated in drilling wells. The two histograms in Figure 4 show the number of wells of a given depth (in 10-foot intervals) and the number of water-bearing fractures penetrated in 10-foot intervals. The data were derived predominantly from the drilling of domestic wells.

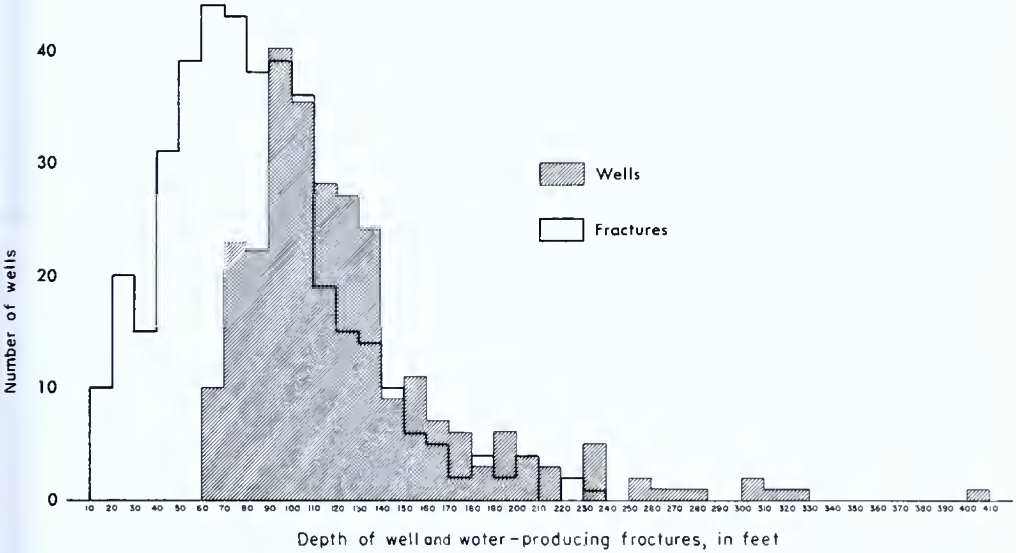


Figure 4. Histograms of well depth and reported depth to water-producing fractures.

The histograms suggest a concentration of openings from 40 to 110 feet in depth. This may be no more than an illusion, because the decrease in number of reported fractures from 100 to 200 feet in depth coincides with the decrease in the number of wells penetrating that depth.

The second line of evidence indicating the depths of yielding zones is from velocity measurements made in the boreholes of 6 wells greater than 200 feet deep, while they were being pumped. The velocity measurements were made by injecting slugs of brine through a plastic tubing into the borehole of the pumped well. The movement of the injected brine slug within the borehole was measured by means of a fluid-conductivity probe and recorded on an electric logging device. The velocity measurements were converted to yield and are shown as a percent of the total pumping yield in Figure 5. Only 1 of the 6 wells obtained any water below a depth of 200 feet.

The two preceding lines of evidence suggest that openings in the rock decrease in number and in water-yielding capacity as the depth increases,

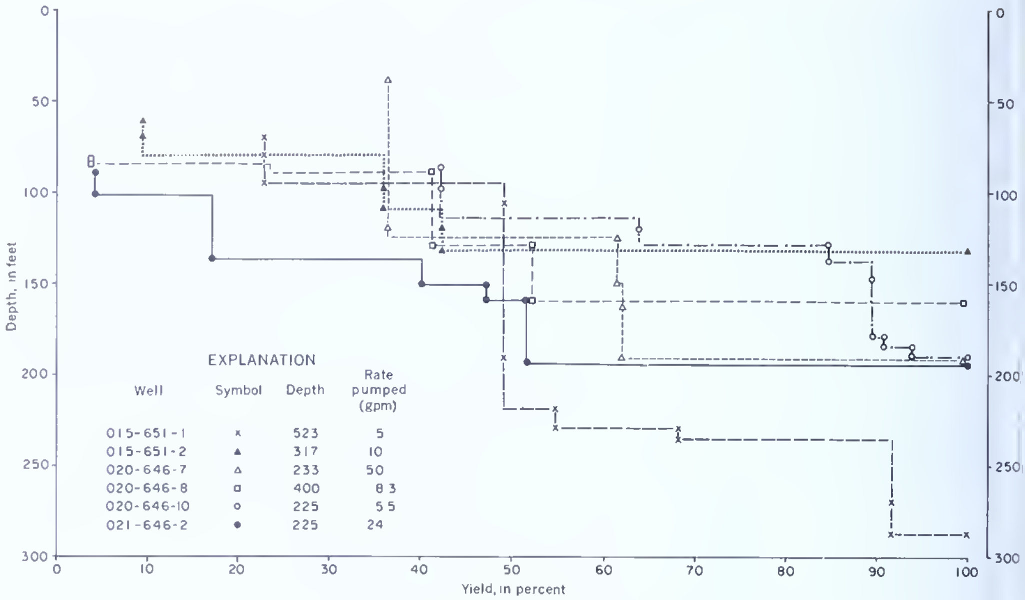


Figure 5. Graph showing percent of yield from joints and other fractures in 6 wells over 200 feet deep in the Martinsburg Formation.

and that few zones of large yield can be expected below a depth of 200 feet.

AVAILABILITY OF GROUND WATER

Data derived from well driller's records indicate that ground water occurs throughout the area underlain by Martinsburg Formation in Dauphin County, and that usually an adequate supply can be found for domestic use. There are, of course, some local exceptions.

Few wells have been drilled into the Martinsburg to ascertain the maximum well yield available. The highest yielding wells drilled for industry or small public supplies do not yield large quantities of water as compared to well yields from the unconsolidated Cretaceous rocks of the Coastal Plain or sands and gravels of Pleistocene age in Pennsylvania.

Reported and measured specific capacities of wells are plotted versus well depth in Figure 6. Two populations of data are shown in this illustration indicating that there is little or no relationship between the reported yields of domestic wells and the availability of ground water—apparently because domestic needs are small, and once they are met no further effort is made to increase the yield. The availability is best demonstrated by the data from wells drilled for commercial, industrial, and public supplies, because large amounts of water are needed and low-yielding wells are not acceptable.

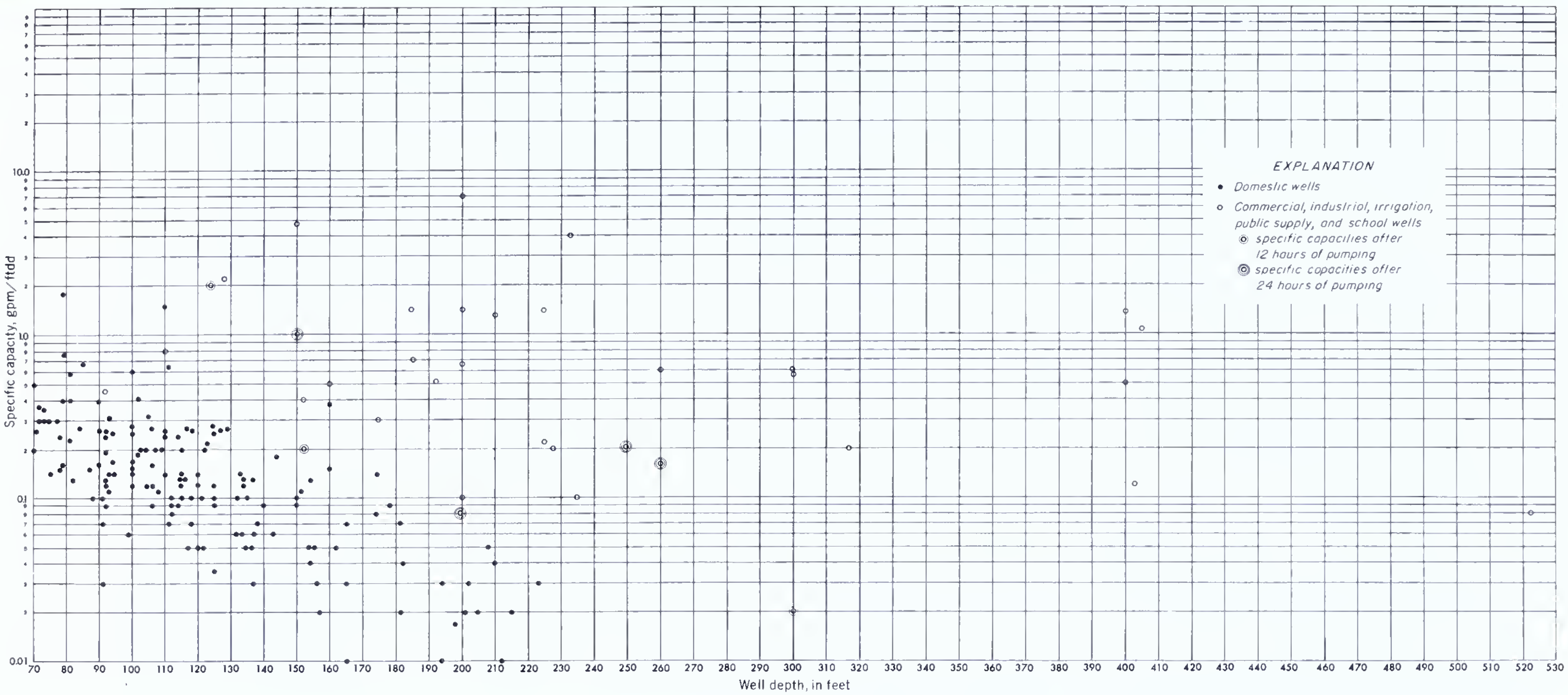


Figure 6. Graph showing a plot of well depth and specific capacity for wells in the Martinsburg Formation in Dauphin County.

The effects of stratigraphy, structure, and topography on the availability of ground water in the Martinsburg are difficult to separate, because rock type (stratigraphy) and joints and other fractures (structures) are the basic controlling factors in forming the topography on the Martinsburg. In general, the highest yields (50 to 200 gpm) are obtained from the limestone member of the Martinsburg; intermediate yields (10 to 50 gpm) are from interbedded sandstone, siltstone, and shale; and the lowest yields (less than 10 gpm) are from an area characterized by sandstone, siltstone, and shale having obscure bedding and prominent cleavage. This area is bounded on the north by a northeast-trending fault extending from southern Harrisburg through Hanoverdale, and on the south by the contact with older carbonate rocks.

WATER-LEVEL FLUCTUATIONS

In a fractured-rock aquifer such as the Martinsburg, ground water occurs under water-table conditions. However, response of the water level in wells to the changes in atmospheric pressure suggest that the aquifer behaves as though semiartesian conditions exist.

Theoretically, in ideal aquifers, ground water occurs under either water-table or artesian conditions. Water-table conditions exist where the upper surface of the zone of saturation (the water table) is not confined but is free to rise or fall in response to changes in the volume of water in storage within the aquifer. In an ideal water-table aquifer, changes in atmospheric pressure are transmitted directly to the water table both in the aquifer and in the well, hence no water-level fluctuation results.

Artesian conditions exist where ground water in a permeable formation is confined under pressure by overlying, relatively impermeable strata. In a well penetrating such an aquifer, the water level will rise above the bottom of the confining bed. Changes in atmospheric pressure produce sizeable water-level fluctuations, because the pressure changes are transmitted more rapidly down the well than through the confining beds. For example, an increase in atmospheric pressure produces a lowering of water levels in wells.

Water-levels in wells penetrating water-table aquifers generally behave to some degree, as if artesian conditions existed, because ideal water-table conditions practically never occur. The strata above the water table generally constitute a partial barrier to the transmisson of atmospheric pressure changes to the water table, and minor fluctuations of water level occur in response to changes in barometric pressure.

Major natural fluctuations of ground-water levels result from the annual cycle of recharge to the ground-water reservoir, during the fall and winter months, and discharge from the ground-water reservoir, during late spring and summer when little recharge takes place. Figure 7 presents graphs showing depth to water table, air-temperature, precipitation, and the base-flow of Paxton Creek. Low water levels in wells and the low base flow of Paxton Creek occur in the summer or growing season, when temperatures are high and evapotranspiration is greatest. In September 1963, when there was essentially no rainfall, the base flow of Paxton Creek increased slightly although the water levels in wells continued to decline. The increase in the base flow of Paxton Creek resulted from decreased evapotranspiration of water from the ground-water reservoir at the end of the growing season.

The range of ground-water fluctuation for 1962 and 1963 was about 7 to 12 feet in the uplands and 2 to 4 feet in the valleys. The minimum ground-water levels coincide with the seasonal minimum in stream levels.

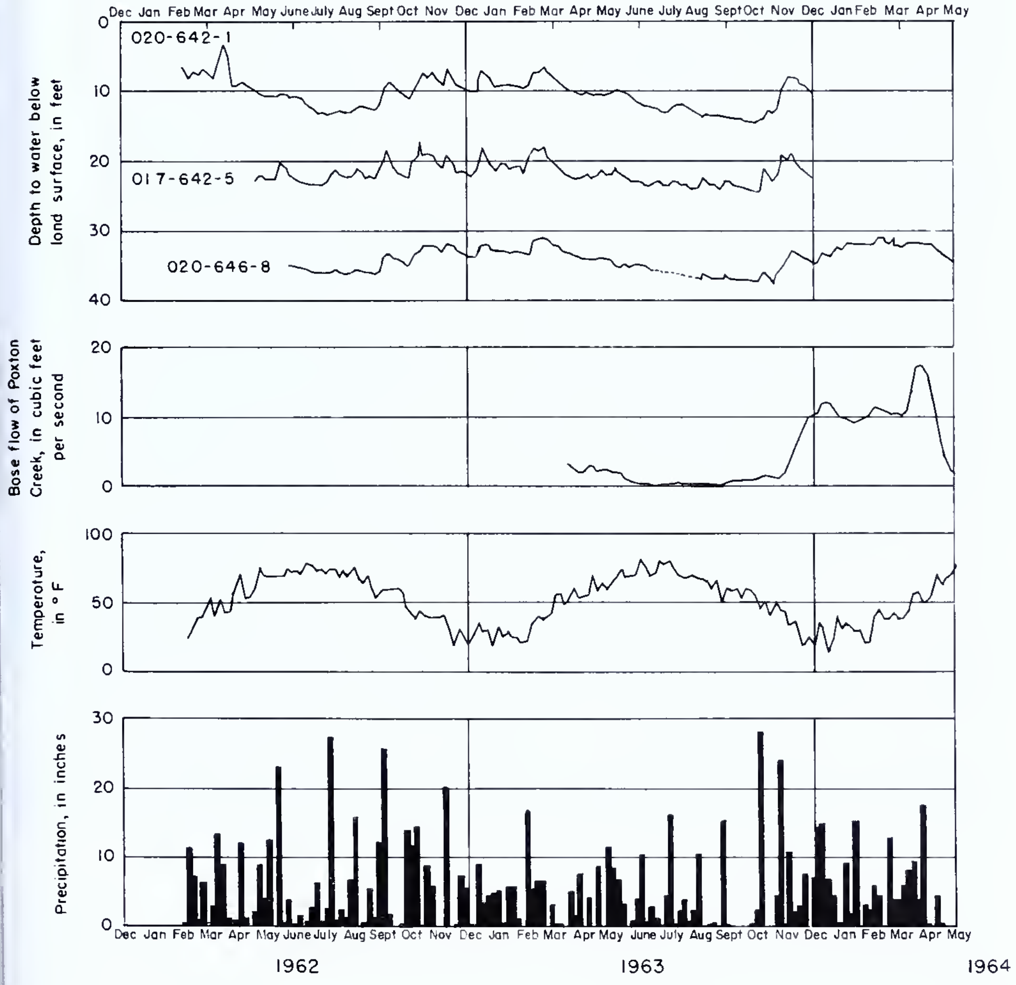


Figure 7. Hydrograph of water-level fluctuations in 3 wells, base flow in Paxton Creek, and 5-day average temperature and total precipitation at the U.S. Weather Bureau at Harrisburg.

Modifications of the seasonal cycle are caused by variations in the intensity and frequency of rainfall in the months of declining water levels and by prolonged freezing periods during the general period of recharge. During spring and fall, when there is little or no consumptive use of water by vegetation, ground-water levels rise quickly in response to precipitation. During the summer months, when vegetation transpires large quantities of water, the trend of declining water levels is reversed only when sufficient precipitaion has fallen to replenish the deficiency of moisture in the soil. Such a situation is shown in Figure 8. Following prolonged dry spells, the soil, rock mantle, and weathered bedrock above the water table can be visualized as behaving like a dry sponge, which transmits water only after absorbing sufficient water to satisfy its own moisture requirements. Because of the need to satisfy first the moisture requirements of the soil, little or no water may be added to the water table by occasional moderate rainfall during summer months.

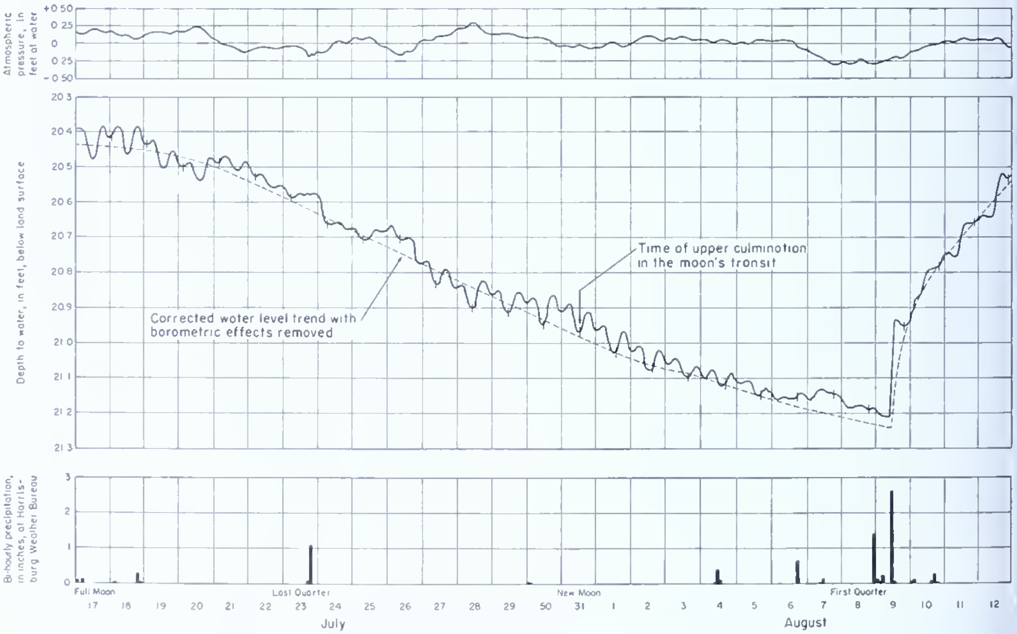


Figure 8. Hydrograph of a well one mile east of Linglestown (020-646-10) from July 17 to August 12, 1962, showing fluctuations of the water table produced by earth tides, changes in barometric pressure, and precipitation.

In the winter months, recharge to the ground-water reservoir takes place during periods of moderate weather, because water cannot be transmitted to the ground-water reservoir when the soil is frozen. Therefore, during periods of prolonged freezing and near-freezing weather, it is not uncommon to have water levels decline temporarily as the reservoir continues to discharge.

During the 90-year period preceding 1964, more precipitation has fallen in the project area during the summer months, or periods of declining water levels, than during the fall and winter when recharge takes place. Lack of precipitation in the summer results in depletion of soil moisture by evapotranspiration and, if prolonged, in injury to the vegetation that draws its moisture from the unsaturated zone. Lack of precipitation during the fall and winter, or period of recharge, may seriously effect the water table the following summer. Adequate precipitation combined with unusual temperature conditions, such as a prolonged cold spell in the late winter followed by a sudden warm spell with warm rains, may cause much of the accumulated snowfall on the surface to run off overland before the ground has had an opportunity to thaw and transmit the water at the surface to the ground-water reservoir.

Minor water-level fluctuations in the area underlain by the Martinsburg are caused by earth tides as the skeletal aquifer of joints and other fractures is expanded twice daily by tidal forces. As the skeletal aquifer expands during the culmination of the moon, water levels drop; and as the tidal forces diminish the skeletal aquifer contracts and the water levels rise again.

Typical diurnal water-level fluctuations caused by earth tides are shown on Figure 8 along with the times of the moon's culmination and phases. Diurnal fluctuations are on the order of 0.1 foot during new and full phases of the moon and diminish to less than 0.01 foot during the first and last quarters.

There is some variation in the amplitude of the diurnal water-level fluctuations between wells. No obvious correlation was observed during this investigation between the amplitude of the diurnal fluctuations and well construction or known geologic, topographic, or hydrologic characteristics. A continuous-recording barometer was operated in the area of investigation during the summer of 1960. A part of this record is shown on Figure 8 and indicates that the efficiency in the response of the aquifer system to changes in barometric pressure is on the order of 20 percent.

Water-level fluctuations resulting from the alternate expansion and contraction of the skeletal aquifer in response to the transmission of earthquake waves was noted in from 1 to 3 wells for four separate earthquakes during the summer and fall of 1963 and for the major earthquake in Alaska on Friday, March 27, 1964. Water-level fluctuations resulting from earthquakes are shown in the following table:

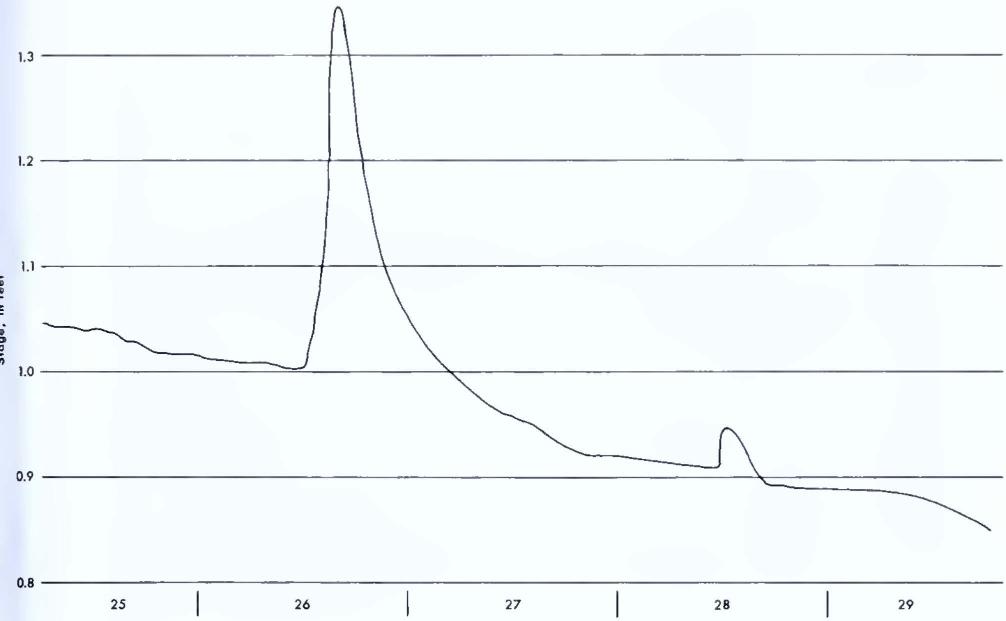
Date	Well number	Total water-level fluctuation (in feet)
9- 3-63	021-647-1	0.04
	021-646-2	.04
10-13-63	020-650-1	.3
	021-646-2	.14
	021-647-1	.08
11-18-63	020-650-1	.06
	021-647-1	.01
	021-646-2	.01
11-23-63	020-650-1	.03
3-27-64	021-646-2	1.+
	021-647-2	1.+
	020-646-8	.81
	020-646-9	.2
	020-646-10	.28

The earthquake-induced water-level fluctuations were typically recorded as a rapid oscillation of water level.

During the summer and fall of 1963 all appreciable water-level fluctuations correlated with earthquakes were from wells in valleys underlain by limestone or by shale. No correlation was found between the amplitude of the 1962 earthquake-induced water-level fluctuations and geologic hydrologic, or well-construction features.

The severe earthquake near Anchorage, Alaska, on March 27, 1964 caused water-level fluctuations in moderately deep (greater than 175 feet) observation wells regardless of topographic location. The water level in in well (020-646-8), on a hilltop, did not return to its previous position after the major water level oscillation had taken place, but showed a net decline of almost half a foot. In well (021-646-2), in a valley, the total water-level fluctuation was more than 1 foot, and there was a net rise in the water level of almost 1 foot. These water-level changes suggest that the alternate expansion and contraction of the aquifer skeleton by the earthquake wave caused permanent changes in the hydraulic properties of the aquifers.

The discharge of Paxton Creek increased suddenly 2 cfs (cubic feet per second) and gradually returned to normal about 12 hours after effects of the earthquake were observed in the wells (shown by the 0.04 foot rise in stage on Figure 9). The increase in discharge of Paxton Creek suggests that a slug of ground water had been suddenly injected at a point upstream No rainfall was recorded for 44 hours before the anomalous increase in flow at either the Weather Bureau at the Harrisburg Airport or at a rain gage operated by Mr. Norman Kapco in the eastern part of the Paxton Creek basin.



igure 9. Hydrograph of Paxton Creek in March 1964, showing increased flow on March 26 resulting from 0.36 inches of rainfall, and an anomalous increased flow on March 28.

WELL TESTS

In uniformly homogeneous material, the cone of depression of the water able or piezometric surface formed by a pumping well is circular in plan iew. In the Martinsburg, where water is transmitted through a non-uniorm, skeletal aquifer of joints and other fractures, the cone of depression in lan view may be elliptical or may even attain a highly irregular shape.

The terms transmissibility and storage used to denote the ability of an quifer to transmit and store water are rigorously defined. However, the keletal aquifer in the Martinsburg, composed of openings along joints, aults, and cleavage, departs widely from the physical conditions of aquier homogeneity and continuity that form the bases of the definition of ransmissibility and storage. Because of the lack of homogeneity in waterearing openings, both horizontally and vertically, the application of conentional terminology to describe the aquifer characteristics is inappropri-te.

Specific capacity is the ratio of discharge to drawdown in a pumped ell and is expressed in gallons per minute per foot of drawdown. The pecific capacity of a well is also a function of time, although this is not llowed for in the definition. Because specific capacity is not defined as a nction of time and is, therefore, definitive for only one particular period of

Table 1. Record of pumping tests

Well number: See section on description of well-numbering system.

Use: I, industrial; S, school; P, public supply; C, commercial; O, observation; D, domestic; Irr, irrigation.

Well number	Pumping rate (gpm)	Length of test (hours)	Total drawdown at end of test (feet)	Specific capacity (gpm per ft dd)	Use
015-651-1	50	1	240++	0.2	I
-2	25	1	317	.08	I
017-651-2	11.5	24	134	.08	S
018-648-1	40	24	170	.24	P
019-646-1	10	6	171	.07	S
-6	6	12	260	.02	I
-8	30	24	16	1.9	S
019-647-1	60	1	100	.6	P
-8	60	24	165	.36	S
019-648-5	30	24	159	.2	C
-6	32-17	24	200	.08	S
019-650-1	48	10	201	.2	P
019-651-5	5	—	67	.07	C
-5	12	—	127	.09	C
-5	18	—	142	.12	C
020-643-1	30	—	55	.54	S
-2	75	12	155	.48	P
020-646-4	24	24	148	.16	P
-5	60	24	59	1	P
-6	25	24	123	.2	P
-7	30	3	10.61	2.8	O
-8	21.5	1.5	21.84	1	O
-9	10	3	35.99	.28	O

Well number	Pumping rate (gpm)	Length of test (hours)	Total drawdown at end of test (feet)	Specific capacity (gpm per ft dd)	Use
-10	20	3	93.64	.21	O
020-647-1	37.5	24	36	1	S
-7	10	2	56.10	.18	D
020-650-1	23.3	2	5.82	4	Irr
-2	195	4	< 95	2+	Irr
021-640-1	50	24	75	.65	S
021-646-2	23.7	1.5	17.30	1.4	O
-3	12.5	1	41.52	.30	D
021-647-1	23	1.6	32.66	.70	O
-2	22.2	1	14.08	1.6	O
022-640-1	47	14	43	1.1	Ind

elapsed pumping, it cannot be relied upon for prediction of changes in water levels for longer periods of pumping. However, under comparable conditions of pumping time and rate, the specific capacities of wells provide an estimate of well performance and a useful relevance for the comparison of the availability of water from wells in different environments—the higher the specific capacity value the better the well. Records of pumping tests made during this investigation are given in Table 1.

In most wells that were test pumped in the Martinsburg, the drawdown of water level in time is such that when drawdown in feet is plotted on an arithmetic scale against the time of pumping in minutes on a logarithmic scale a straight line relationship results after the first few minutes of pumping, and in some wells it continues throughout the pumping test. In many other wells this straight line relationship does not continue indefinitely, but reaches a point where the rate of drawdown increases or decreases, then the time-drawdown plot swings through an arc, after which the points again fall on a straight line. Typical examples of the semilogarithmic time—drawdown plots are shown in Figure 10. The increases or decreases in the rate of drawdown in the pumped well are believed to reflect boundary conditions and can be visualized as changes in the shape and rate of expansion of the cone of depression formed around the pumped well.

An increase in the rate of drawdown in time results when one edge of the expanding cone of depression reaches impermeable or only poorly permeable rock that hinders its further expansion in that particular direction. As a consequence, the cone is deepened in order to compensate for the limiting of the expansion of the cone. Conversely, a decrease in the rate of drawdown occurs when the expanding cone of depression about the well intercepts more permeable beds, solution openings, or a surface body of water such as a stream or lake, thereby increasing the source of supply available to the pumped well. Further drawdown in the well is reduced in proportion to the amount of water provided to the well by the new source.

Sharp downward breaks in the time-drawdown plot may occur when water-filled fractures or openings are drained, thereby temporarily reducing the thickness of the aquifer through which water is transmitted to the well.

The best of the wells represented in Figure 10 are those having the flattest drawdown curves and the least amounts of drawdown. (Well 021-647-2 for example.) The poorest wells are those with the steepest curves. However, most of the steep curves are trending toward stabilization in the next log-cycle. The curve for well 020-647-7, however, is trending toward depletion within the log-cycle.

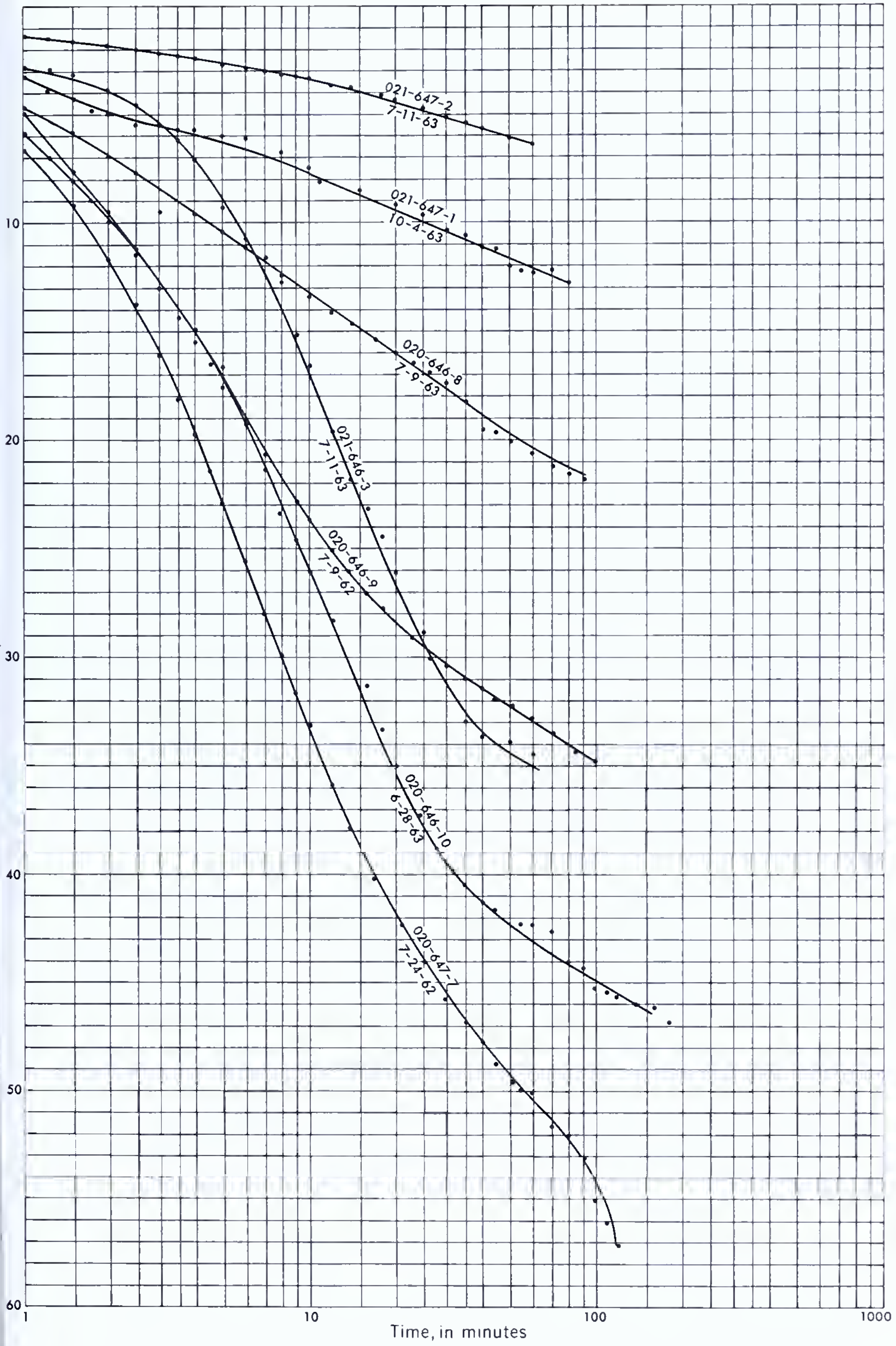


Figure 10. Semilogarithmic graph of drawdown in 7 wells pumped at 10 gallons per minute.

WELL DEVELOPMENT

Only the simplest well-development techniques have been utilized in the past in the Martinsburg Formation in Dauphin County. Wells were drilled until adequate yield was obtained for expected needs or until increasing drilling costs made further drilling prohibitive. Upon obtaining an adequate water supply, drillers usually bailed or pumped the well until the water cleared. If the well was drilled by a cable tool, a bailer was used; if it was drilled by an air rotary drill, the well was pumped by air lift.

The effectiveness of another well-development technique was evaluated during the present investigation by adding a chemical cleaner and surging two wells. Pumping tests were made on both wells before and after this method of development.

Test well 020-646-10, which was drilled in 1962 by an air rotary drill to 225 feet and yielded 7 gpm, was developed in two steps. In June 1963 the water level in the well was lowered by bailing from the original water level of 20 feet below land surface to 225 feet in 30 minutes. At this depth, 2 minutes were required to fill the 15-gallon bailer. For the next 6 hours the well was alternately surged with a surge block and bailed. A pumping test made the following day showed that surging had improved the well. A graphical plot of the drawdown during test pumping before and after the surging (see Fig. 11) illustrates the improvement. The specific capacity based upon 30 minutes of pumping was improved about 67 percent.

Upon completion of the pumping test, 115 pounds of commercial well conditioner (chiefly hexametaphosphate) was poured in the well, and water in the well was recycled by pumping until the cleaner was considered to have been thoroughly mixed with water in the borehole. The well was surged for 8 hours using a surge block, and then it was surged and bailed alternately for 4 additional hours. After development, the water level in the well could not be lowered more than 120 feet below the land surface by bailing 20 to 30 gpm for 1 hour. The well was again tested by pumping and the results showed an additional improvement. The specific capacity based on 30 minutes of pumping was improved about 40 percent. The total improvement in specific capacity was 133 percent.

Well 021-647-1 was treated with hexametaphosphate as follows: the dry material was added to the well and the well pumped at a rate of 23 gpm into a 55-gallon barrel. When the barrel was full the pump was turned off and the well was allowed to recover to within 5 feet of the original level. The aqueous solution in the barrel was then re-injected at a rate of about 15 gpm. This procedure was repeated 10 times. The well was then pumped for 100 minutes, at which time the water being discharged was clear. After allowing the well to recover overnight a pumping test was made to measure improvement in the yield of the well. A plot of the

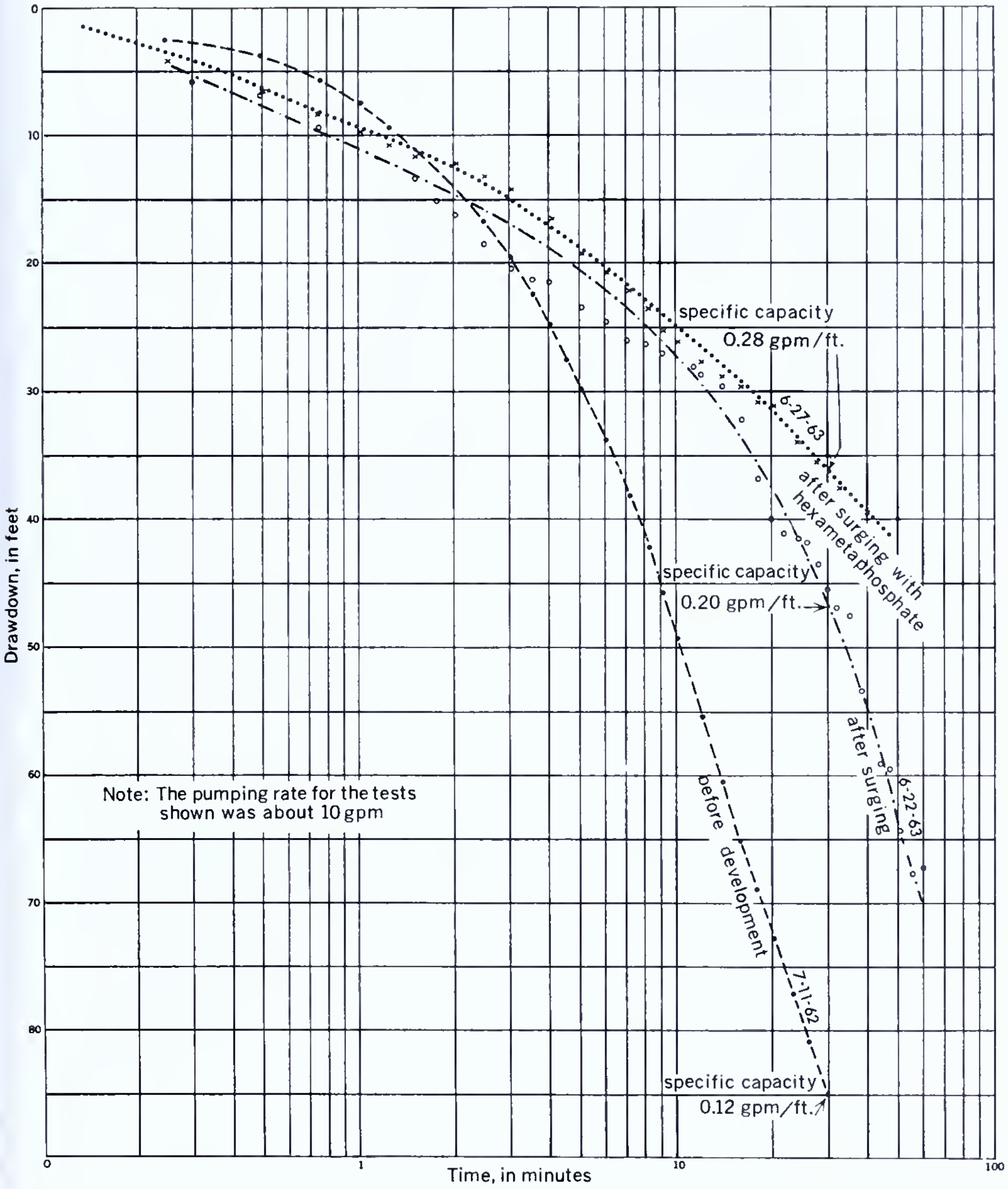


Figure 11. Graph of drawdowns in well 020-646-10 showing the effect of well development.

drawdown during the test shows the improvement. (See Fig. 12.) The specific capacity, based upon 1 hour of pumping, was improved about 24 percent.

The small improvement in yield shown after the development of well 020-647-1 is probably the result of the development technique. The phosphate was much less soluble than had been anticipated, and most of it probably settled to the bottom of the well as an inert mass. In addition, the depth to which the submersible pump could be set for development was limited by available electric cord to 100 feet. Thus, the circulation of

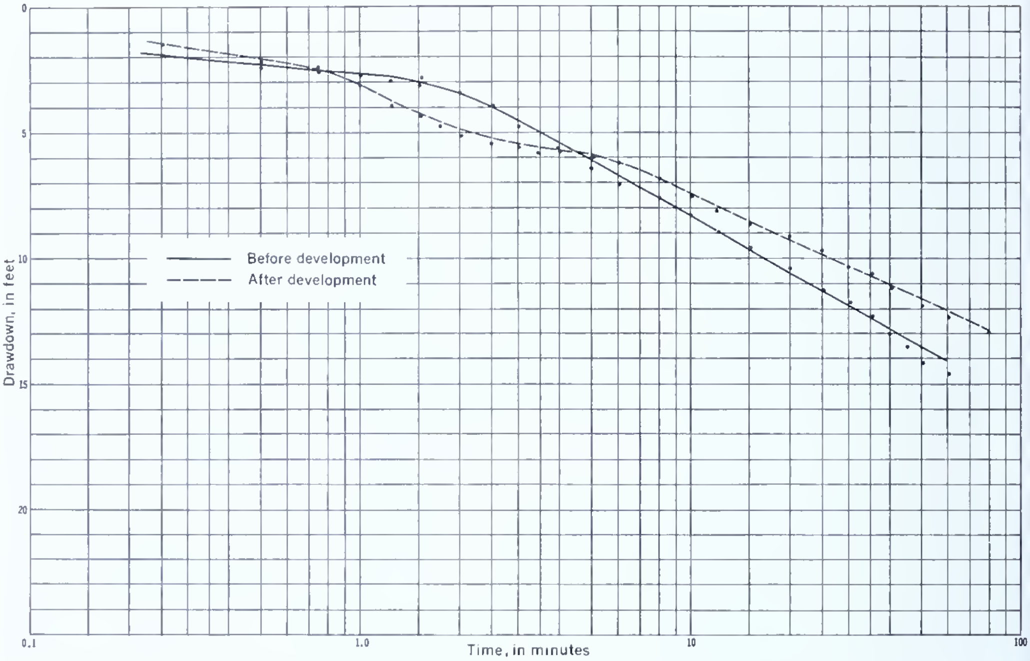


Figure 12. Semilogarithmic graph of drawdown in well 021-647-1 before and after development, using hexametaphosphate.

the aqueous solution of hexametaphosphate was limited to the upper 100 feet of the borehole. Any minor water-bearing fractures penetrated by the well below 95 feet would probably remain sealed off by mud.

Additional data on the extent of development was furnished by fluid-conductivity measurements made nine months after development. The fluid-conductivity measurements showed the lower 90 feet of the well to have a large amount of the hexametaphosphate still present in the borehole. No movement of water occurred in the borehole below 95 feet when the well was pumped at 23 gpm. If hexametaphosphate is used for future development of wells in the Martinsburg, it should be dissolved before it is added to the well. Also the discharge hose of the pump should be placed in the well so that the water could be recycled continuously. Although well 021-647-1 is 185 feet deep, it apparently yields water only in the upper 95 feet of the borehole.

EFFECT OF URBANIZATION ON BASE FLOW OF PAXTON CREEK

A gaging station was maintained on Paxton Creek, north of Harrisburg (see Plate 1), between 1941 and 1950. The gaging station was re-established in April 1963 to measure, over a period of one climatic year, any change in the stream regimen as a result of urbanization. Between 1950 and 1963 most of the basin underwent a transformation from a rural agricultural environment to that of a semirural environment in which homes were built on large plots and were interspersed with schools, churches, and shopping centers. The base flow of Paxton Creek for the 1963 climatic year was compared with the base flows of the previous years of record. During the base-flow period in 1943, when the rainfall was comparable to that of the base-flow period in 1963 but the antecedent rainfall was greater, the base flow diminished below 0.1 cfs; however, during the base-flow period in 1963, when the rainfall was comparable to that of the 1943 base-flow period but the antecedent rainfall was less, the base flow was sustained above 0.21 cfs. (See Fig. 13.) Also, minimum flows of Paxton Creek for 3 to 7 consecutive days were compared with those of Swatara Creek at Harpers Tavern, Lebanon County, for the 1963 base-flow period, and it was confirmed that the base flow of Paxton Creek was sustained over that determined from the 1941 to 1950 records by about 26,000 gpd. This is probably a result of changes in the natural recharge-discharge relationship brought about by importing water into the basin and releasing it into the ground as septic-tank effluent. The septic-tank effluent is usually released via a drain field to the ground-water reservoir where it flows directly into nearby streams.

QUALITY OF WATER

Ground water undergoes a sequence of changes as it tends continuously to adjust to the geologic and hydrologic environment while moving from points of recharge to points of discharge. The degree to which chemical equilibrium is attained at any one position in the flow network is largely dependent on the initial composition of the water entering the environment, the composition of the rock within the environment, the surface area of the rock in contact with the water, and the velocity of the water—which determines how long it remains within the specified environment. Unfortunately, the quality of water in different environments in the ground-water part of the hydrologic cycle in the Martinsburg in Dauphin County cannot be described in detail at present. The reason such a description is not possible is the lack of data on the composition of rain water and water in the soil above the water table and because of the difficulty in collecting samples of water for chemical analyses in sequence along a flow path.

The position of a flow path can only be determined in a gross way. In fractured sedimentary rocks it is rarely possible to know precisely where the water enters the borehole unless measurements are made. Typically, water pumped out of the well represents a blend of water derived from several different producing zones within the well. Any well intercepting water-producing horizons distributed through the length of the borehole

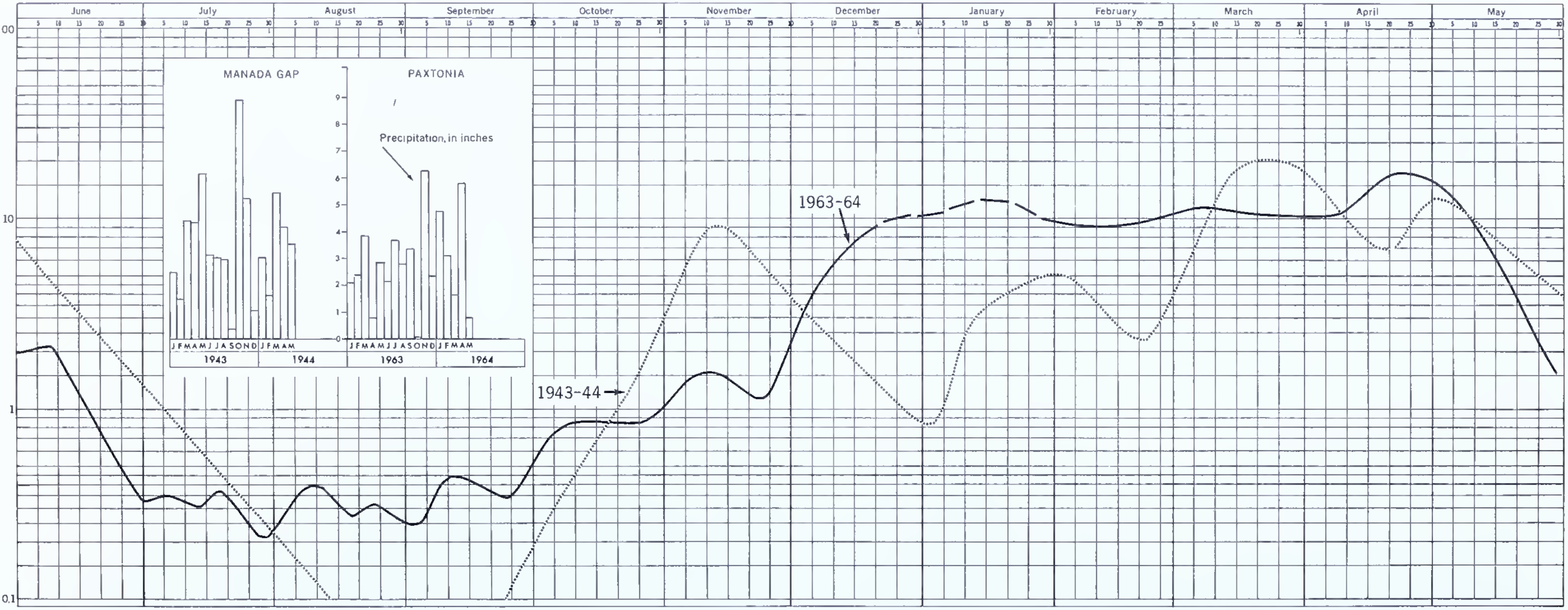


Figure 13. Base flow of Paxton Creek and monthly precipitation in Paxton Creek basin for the 1943 and 1963 climatic years.

will usually exhibit internal flow within the well—from joints and other fractures where the water is under a high hydraulic head to joints and other fractures where the water is under a low hydraulic head. In the Martinsburg Formation of Dauphin County, wells in the uplands or hills generally have downward internal flow, and wells in the valleys generally have an upward internal flow. Therefore, water derived from pumping wells in the uplands for a short time, may have chemical characteristics of water near the surface, regardless of the well depth. The water pumped from wells in valleys, however, will generally have the chemical characteristics of water entering the well at depth, and such water has probably traveled a considerable distance through the aquifer.

To study the chemical characteristics of the ground water in the Martinsburg Formation of Dauphin County, 34 samples of well water were col-

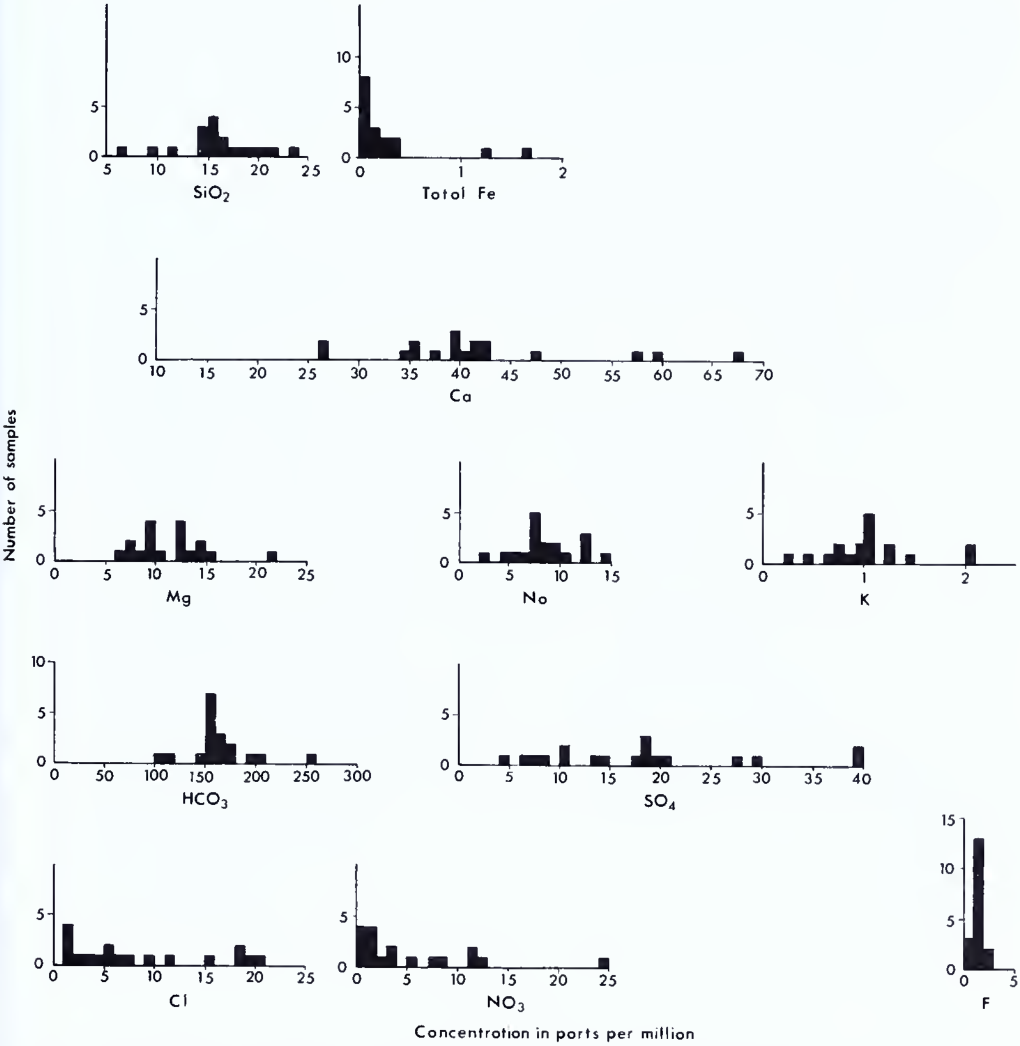
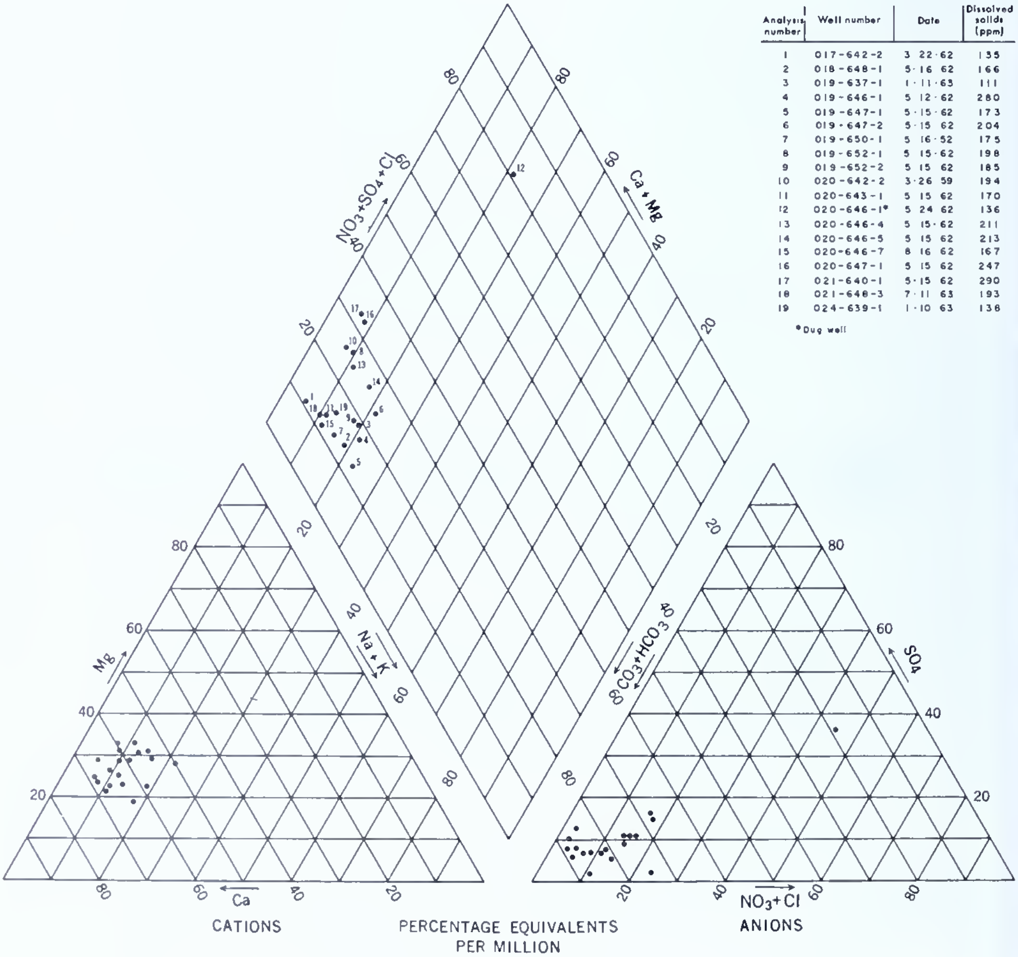


Figure 14. Histograms showing the range and distribution of concentration of dissolved substances in samples of ground water from the Martinsburg Formation.

lected for chemical analyses. One sample was collected from Paxton Creek, for comparison with three samples taken from Paxton Creek during an earlier project. Sixteen of the samples were collected with a point sampler from different depths in four of the test wells drilled during this investigation. Results of chemical analyses are shown in Table 3 and on Figure 14.

Ground water in the Martinsburg Formation in Dauphin County is hard, very slightly alkaline, and is chiefly of the calcium bicarbonate type—evidenced by the trilinear diagram (Piper, 1944) shown in Figure 15. The major cations, in order of abundance, are: calcium, magnesium, sodium, potassium, and iron. The major anions, in order of abundance, are: bicarbonate, sulfate, nitrate, chloride, and fluoride. The range in concentration of each of these constituents is shown in Figure 14.



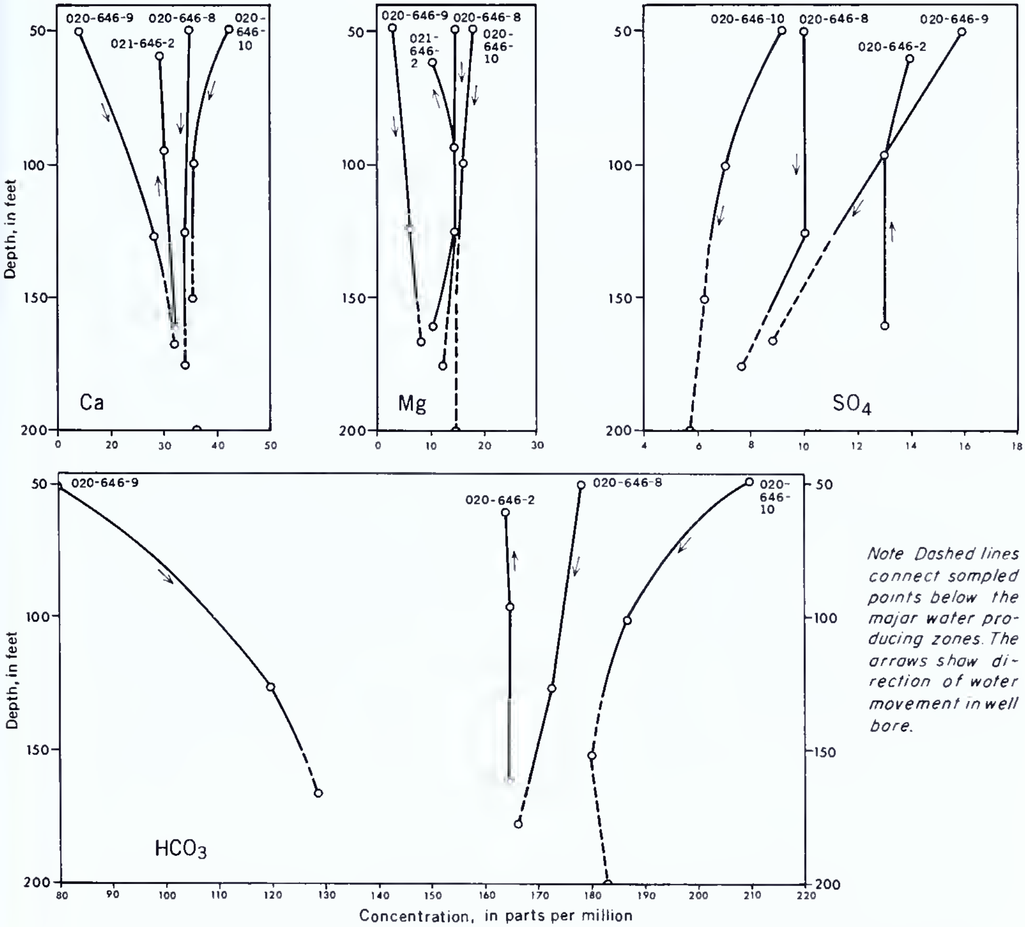
Analysis number	Well number	Date	Dissolved solids (ppm)
1	017-642-2	3-22-62	135
2	018-648-1	5-16-62	166
3	019-637-1	1-11-63	111
4	019-646-1	5-12-62	280
5	019-647-1	5-15-62	173
6	019-647-2	5-15-62	204
7	019-650-1	5-16-52	175
8	019-652-1	5-15-62	198
9	019-652-2	5-15-62	185
10	020-642-2	3-26-59	194
11	020-643-1	5-15-62	170
12	020-646-1*	5-24-62	136
13	020-646-4	5-15-62	211
14	020-646-5	5-15-62	213
15	020-646-7	8-16-62	167
16	020-647-1	5-15-62	247
17	021-640-1	5-15-62	290
18	021-648-3	7-11-63	193
19	024-639-1	1-10-63	138

*Dug well

Figure 15. Trilinear diagram of chemical analyses of ground water in the Martinsburg Formation.

CHANGES IN COMPOSITION OF GROUND WATER ALONG FLOW PATHS

Sixteen samples of ground water were collected with a point sampler consisting of a hollow cylinder with ball valves at top and bottom. Samples were collected from 3 different depths in 2 wells and 4 different depths in another—all wells being about 200 feet deep. Samples were collected from 6 different depths in one test well 400 feet deep. In all of these wells, mixing of ground water is presumed to have taken place by means of internal flow within the well bore. In three closely spaced wells on a small hill (wells 020-646-8, 9, and 10), water from higher parts of the formation moves into and down the borehole and out through openings lower in the borehole; and in a nearby well in a valley (well 021-646-2), there is upward circulation in the borehole—presumably discharging into fractures near the surface. The concentration, in parts per million, of the major cations and anions are plotted against depth in Figure 16.



Note Dashed lines connect sampled points below the major water producing zones. The arrows show direction of water movement in well bore.

Figure 16. Graph showing relationships between concentrations of major ions and depth.

There is little difference in the composition of the samples collected at different depths from well 021-646-2, which is in a valley and the deep well, 020-646-8, which is on a hill. Brine tracing of the well in the valley showed internal upward flow of 3 gallons per hour originating predominantly from a solution opening at 195 feet; brine tracing of the well on the hill showed moderate downward circulation of borehole water to the depth of 160 feet; however, the uniform chemical composition of the water at each point sampled in the well suggests that enough water is moving down the well from above the 50 foot sample to cause a uniform mixture throughout the well.

In wells having downward internal circulation (wells 020-646-9, and 10) the plot (see Fig. 16) of the concentrations of the following cations and anions converge with depth: calcium, magnesium, sulphate, and bicarbonate—as do specific conductance and dissolved solids. Except for sulphate the plot shows convergence, in general, toward the amount of concentration found in the discharge well 021-646-2 and toward the approximate areal mode of each constituent.

Several wells drilled in valleys in the Martinsburg, in the northern part of the area near the base of Blue Mountain, yield water high in hydrogen sulfide. The hydrogen sulfide content of samples collected from well 021-647-2 at depths of 60, 110, and 160 feet below land surface are 1.3, 2.0, and 0. 5 ppm, respectively.

Minor time-variations in the quality of ground water can be documented for some areas, and these changes are believed to be a direct result of the activities of man. Changes in the chloride concentration of ground water being utilized in two small housing developments east of Harrisburg are shown in Figure 17. All but two of the analyses are by the courtesy of the Pennsylvania Department of Health, Division of Sanitary Engineering. Both developments utilize one or two centrally located drilled wells to supply water. There are no sanitary sewers in either development, and septic tanks are used for sewage disposal. The central water-supply system in both housing developments was started in 1954. The concentrations of chloride in both water supplies was 1 ppm or less when originally sampled. There has been an increase in concentration of chloride in time in both supplies.

Chlorine in the form of hypochlorite is added to both water systems, in accordance with State laws, by the water companies operating the systems. The amount of chloride added in this way is probably small, whereas a large amount of chloride is added to water during domestic use in a variety of forms before the water is disposed of in septic tanks. The continued injection of chloride-enriched waste waters is believed to have increased the chloride content of the ground water in these areas.

The increase in the chloride concentration does not necessarily imply a recycling of large quantities of water in these developments. The movement of chloride to the ground-water zone could be largely seasonal, be-

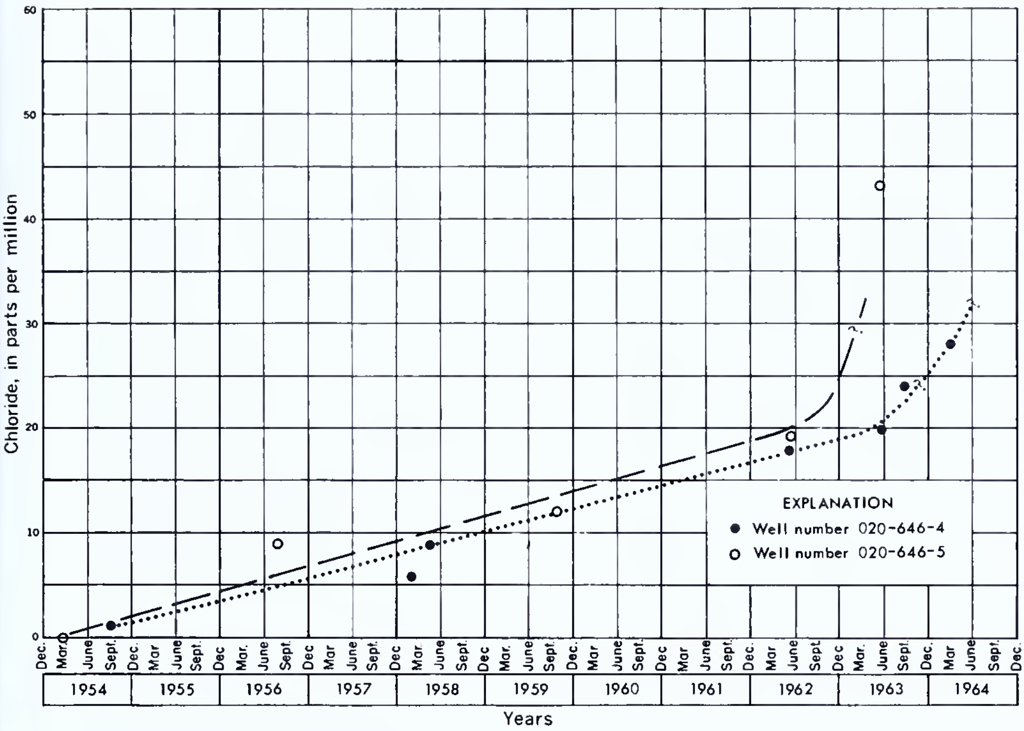


Figure 17. Graph showing increases in chloride concentration in time for well 020-646-4 and 020-646-5.

cause waste water during the summer is injected into the near-surface zone of evapotranspiration, where the chloride could be concentrated during the summer months and leached during times of recharge.

Samples from wells that are known to be uncontaminated contain 6 to 10 times more soduim (in equivalents per million) than chloride. Therefore, samples having a ratio significantly less than 6 to 1 suggest the addition of chloride to the aquifer by man. Water from the wells showing increasing concentrations of chloride in time (wells 020-646-4, and 5) have approximately equal concentrations of sodium and chloride in equivalents per million.

Sulfate, nitrate, and alkyl benzene sulfonate (ABS) are also generally considered to be indications of pollution (Walton, 1961). Neither the sulfate nor the nitrate concentrations of the ground water in either of the two housing developments appears to have changed appreciably with time, and they are not significantly different than concentrations in some ground water in areas where contamination is not believed to exist. In those water samples from each development that were analyzed by the U.S. Geological Survey, Quality of Water Branch, the concentrations of phosphate and ABS—major ingredients of household detergents—were too minor to be significant.

Comparison of two analyses of water from Paxton Creek that were made in late summer and fall of 1963 with analyses made in 1944 and 1945 suggests an increase in the chloride content of Paxton Creek with time. Chloride contents of samples collected August 10, 1944 and March 21, 1945 were 3.2 and 2.6 ppm, respectively, whereas the chloride contents of samples collected September 6, 1963 and October 18, 1963 were 11 and 14 ppm respectively. This change in chloride content with time is believed to be caused by pollution resulting from the continued urbanization of the Paxton Creek drainage basin.

Alkyl benzene sulfonate (ABS) is the most abundant ingredient of detergents found in ground and surface waters, because it resists both biological and chemical degradation. Because of widespread concern over synthetic detergents in the ground water of rapidly expanding suburbs in other parts of the country (Campenni, 1961), the possibility of the presence of ABS in the ground water of the Martinsburg Formation in Dauphin County was investigated. Samples were taken at random from 15 stream sites and 30 water wells and analyzed by the methylene blue procedure (AWWA Task Group report, 1958). Most ABS concentrations were below 0.1 ppm, which is considered insignificant, because in this method of analysis some interfering substances cause apparent high ABS concentrations (Walton, 1961, and Wayman, 1962).

Wells can be contaminated by near-surface waters that enter through leaky casing or well seals or because of insufficient or inadequately grouted casing. M. S. Bistline, Lower Paxton Township Sanitary Officer, reports (personal communication) that in almost all cases of contamination of wells in the Martinsburg that he has investigated, the condition was corrected by properly sealing, or casing, grouting, sealing, and disinfecting the well. He reported two locations where the contaminated well could not be related to faulty conditions of the well casing and seal; these examples suggest contamination of the aquifer. Subsequent geologic mapping revealed that these two locations were underlain by the limestone member of the Martinsburg, and because contamination of ground water in limestone is a common occurrence it is reasonable to expect contamination to occur in the limestone members of the Martinsburg.

The ABS content of ground water was investigated in two areas underlain by Martinsburg limestone. In one area, samples were collected from three wells drilled in the limestone member and from one well in the adjacent shale. In the other area samples were collected from six wells drilled in the limestone member and from two wells drilled in the adjacent shale. One third of the samples taken from wells in limestone in each area contained significant amounts of ABS (0.5 ppm). None of the samples from the wells in shale contained significant amounts of ABS.

The extent of the addition of ABS to ground water was investigated by collecting 18 samples from wells in Linglestown, an old established community of closely spaced houses in which the water supply is obtained from individual wells, and sewage is discharged into septic tanks. Significant amounts of ABS were found in 7 of the 18 samples collected in Linglestown. However, the large scale addition of ABS to the ground-water reservoir at Linglestown could not be conclusively demonstrated, because details of well construction of old wells is difficult to acquire, and it is not known whether the water containing significant amounts of ABS entered the wells from the top, because of faulty well seals or casing, or through the skeletal aquifer of joints and faults.

ABS is removed from water by adsorption on kaolinite, a common clay mineral (Wayman, and others, 1963), and may be adsorbed on other clay minerals; therefore, much of the ABS injected into the Martinsburg Formation may possibly be adsorbed in clays in highly weathered shale.

CONCLUSIONS

In Dauphin County, Pennsylvania the Martinsburg Formation is composed chiefly of shale or shaly siltstone. Minor rock types include siliceous shale or chert, thin-bedded shaly limestone, limestone edgewise conglomerate, clayey dolomite, sandstone, and graywacke. The structure of the Martinsburg is extremely complex. North of a thrust fault that extends northeast from Harrisburg to near where U.S. Route 22 enters Lebanon County, some bedding can be observed in exposures of the Martinsburg. Most of the beds are nearly vertical or dip steeply to the south, and they strike north 70° to 90° east. South of the thrust fault bedding is mostly obscured by intense deformation.

The most favorable topographic locations for obtaining the highest-yielding wells in the Martinsburg are in the upland stream valleys. Ground water is stored and transmitted through an aquifer composed of openings along joints, faults, and bedding planes. Development and enlargement of these openings are the result of solution and removal of the rock by circulating ground water, and upland stream valleys are the most favorable environment for the solvent action of circulating ground water.

Fracture openings in the Martinsburg decrease in number and size as the depth increases. Most wells receive water from yielding zones less than 200 feet deep. Wells drilled deeper than 200 feet can increase the total yield of the well; however, few water-yielding zones have been measured below 200 feet.

Well development was determined to be an effective tool for increasing well yields in the Martinsburg. Development of well 020-646-10 by surging and bailing improved the well's specific capacity 67 percent. By adding a commercial well conditioner to this well and surging, the specific capacity of the well was improved an additional 40 percent.

Yields of 10 to 50 gpm are obtained from most wells in the Martinsburg Formation (excluding carbonate rocks) north of the thrust fault that extends northeast from Harrisburg. Wells south of this fault have yields of less than 10 gpm. The highest yielding wells (50 to 200 gpm) are in the limestone; however, the limestone constitutes a very small part of the Martinsburg Formation.

Water from one third of the wells in the limestone member of the Martinsburg contains ABS (a principal ingredient of household detergents) which is considered evidence that the aquifer is being contaminated by septic-tank effluent. Most wells in non-carbonate rocks were free of ABS; however, one third of the wells in non-carbonate rocks in an old established community were found to contain ABS. This contamination of wells is believed to be local and the result of old and faulty well construction.

REFERENCES

Behre, C. H., Jr. (1926), *Observations on structures in the slates of Northampton County, Pennsylvania,* Jour. Geology, v. 34, p. 481-506.

Berry, W. B. N. (1963), *On the "Snake Hill Shale,"* Am. Jour. Sci., v. 261, p. 731-737.

Bricker, Owen (1960), *Ordovician volcanics of the Bunker Hills, Lebanon County, Pennsylvania,* Guidebook for 25th Annual Field Conference of Pennsylvania Geologists, p. 92-97.

Campenni, L. G. (1961), *Synthetic detergents in ground water—Part 1,* Water and Sewage Works, v. 108, no. 5, p. 188-191.

Cooper, B. N. and Cooper, G. A. (1946), *Lower Middle Ordovician stratigraphy of the Shenandoah Valley, Virginia,* Geol. Soc. America Bull., v. 57, no. 1, p. 35-113.

Craig, L. C. (1949), *Lower Middle Ordovician of south-central Pennsylvania,* Geol. Soc. America Bull., v. 60, p. 707-779.

Drake, A. A., Jr., Davis, R. E., and Alvord, D. C. (1960), *Taconic and Post-Taconic folds in eastern Pennsylvania and western New Jersey,* U.S. Geol. Survey Prof. Paper 400-B, p. B180-B181.

Ellis, E. E. (1906), *Occurrence of water in crystalline rocks,* U.S. Geol. Survey Water Supply Paper 160, p. 19-28.

Fettke, C. R. (1948), *Subsurface Trenton and sub-Trenton rocks in Ohio, New York, Pennsylvania, and West Virginia,* Am. Assoc. Petroleum Geol. Bull., v. 32, p. 1457-1492.

Geyer, A. R., Gray, Carlyle, McLaughlin, D. B., and Moseley, J. R. (1958), *Geologic map of the Lebanon quadrangle,* Pennsylvania Geol. Survey, 4th Ser., Atlas 167-C.

Grabau, A. W. (1909), *Physical and faunal evolution of North America during Ordovicic, Siluric and early Devonic time,* Jour. Geology, v. 17, p. 209-252.

Hall, George Martin (1934), *Ground-water in southeastern Pennsylvania,* Pennsylvania Geol. Survey, 4th ser., Bull. W-2, 255 p.

Kay, G. M. (1941), *Taconic allochthone and the Martic thrust,* Science, new ser., v. 94, p. 73.

Lesley, J. Peter, and others (1891), *Geological map of Dauphin County, Pennsylvania,* Second Pennsylvania Geol. Survey, Rept. X.

Maxwell, J. C. (1962), *Origin of slaty and fracture cleavage in the Delaware Water Gap area, New Jersey and Pennsylvania,* Geol. Soc. America, Buddington vol., p. 281-311.

McBride, E. F. (1962), *Flysch and associated beds of the Martinsburg Formation (Ordovician), central Appalachians,* Jour. Sed. Petrology, v. 32, p. 39-91.

Miller, Benjamin L. (1926), *Taconic folding in Pennsylvania,* Geol. Soc. America Bull., v. 37, p. 497-512.

Miller, Ralph L. (1937), *Martinsburg limestones in eastern Pennsylvania,* Geol. Soc. America Bull., v. 48, p. 93-112.

Moseley, J. R. (1952), *Limestones within the belt of the Martinsburg Group in Lebanon County, Pennsylvania,* Pennsylvania Acad. Sci., Proc., v. 26, p. 78-85.

——— (1954), *Cross faults in the Martinsburg Formation, Lebanon County, Pennsylvania,* Pennsylvania Acad. Sci., Proc., v. 28, p. 135-142.

Piper, A. M. (1944), *A graphic procedure in the geochemical interpretation of water analyses,* Am. Geophy. Union Trans. v. 25, p. 914-923.

Prouty, C. E. (1959), *The Annville, Myerstown and Hershey Formations of Pennsylvania,* Pennsylvania Geol. Survey, 4th ser., Bull. G-31, 47 p.

Ruedemann, Rudolf (1942), *Cambrian and Ordovician fossils,* New York State Mus. Bull. 327, p. 19-32.

Stose, G. W. (1930), *Unconformity at the base of the Silurian in southeastern Pennsylvania,* Geol. Soc. America Bull., v. 41, p. 629-658.

——— (1946), *The Taconic sequence in Pennsylvania,* Am. Jour. Sci. v. 244, p. 665-696.

Swartz, F. M. (1948), *Trenton and sub-Trenton of outcrop areas in New York, Pennsylvania and Maryland,* Am. Assoc. Petroleum Geologists Bull. v. 32, p. 1493-1595.

Task Group Report (1958), *Determination of synthetic detergent content of raw-water supplies,* Jour. Am. Water Works Assoc., v. 50, p. 1343-1352.

Theokritoff, George (1964), *Taconic stratigraphy in northern Washington County, New York,* Geol. Soc. America Bull., v. 75, p. 171-190.

Walton, Graham (1961), *Chemical indicators of sewage contamination of ground water,* Water Well Jour., v. xv, no. 3, p. 22-23, 42, 47-51.

Wayman, Cooper H. (1962), *Limitations of the methylene blue method for ABS determinations,* U.S. Geol. Survey Prof. Paper 450-B, p. B117-B120.

Wayman, C. H., Robertson, J. B., and Page, H. G. (1963), *Adsorption of the surfactant ABS on kaolinite,* U.S. Geol. Survey Prof. Paper 450-E, p. E181-E183.

Willard, Bradford (1938), *Lower Ordovician, Lehigh and Delaware Valleys,* Pennsylvania Acad. Sci. Proc., v. 32, p. 177-183.

Willard, Bradford, and Cleaves, A. B. (1938), *A Paleozoic section in south-central Pennsylvania,* Pennsylvania Geol. Survey, 4th ser., Bull. G-8, 38 p.

Zen, E-an (1959), *Problem of the Hortonville Formation in west-central Vermont* [*abs*], Geol. Soc. America Bull., v. 70, p. 1705.

Table 2. Record of wells in the Martinsburg Formation

Well number: See section on description of well-numbering system.
Method of construction: Dr, drilled; Du, dug.
Total depth: Reported, if no date of measurement is given.
Aquifer composition: ss, sandstone; ls, limestone; sh, shale; ch, chert.
Static water-level, depth below land-surface: Reported, if no date of measurement is given.

Use: A, abandoned; D, domestic; I, industrial; Irr, irrigation; O, observation; Ps, public supply; S, school; C, commercial.
Remarks: CA, chemical analysis in Table 3; Dd, drawdown during bailer test; EL, electric log available; H_2S, hydrogen sulfide reported, PT, pumping test; WLR, water-level recorder; ABS, alkyl benzene sulfonate (detergent).

Well number	Owner	Driller	Date completed	Altitude above sea level (feet)	Method of construction	Diameter of casing (inches)	Total depth (feet)	Reported depth to bottom of casing (feet)	Aquifer composition	Static water level		Reported yield (gpm)	Use	Remarks
										Date measured	Depth below land surface (feet)			
015–646–1	Justine Tasebner	Kohl Bros.	7–18–60	500	Dr	6¼	104	47	sh		15	18	D	
015–651–1	Megs Macaroni Co.	do	1–31–62	490	Dr	6¼	317	20			10	35	I	Dd. 250 ft. in 24 hrs.
–2	do.	do.	1–31–62	490	Dr	6¼	523	13			15	23	I	Dd. 345 ft. in 4 hrs.
016–642–1	L. Dean Fromm	do.	12–16–60	500	Dr	6¼	201	38			30	4	D	
016–643–1	R. Dininni Const Co.	do.	4–27–64	450	Dr	6¼	312	43	sh		50	2	D	
–2	R. E. Deilmer	Ralph Myers		410	Dr		300	30			28	1	D	
016–644–1	S. W. Patten	Kohl Bros.	6–17–60	360	Dr	6¼	165	52	sh		40	10	D	
–2	Betty J. Cassatt	C. H. Eichelberger		440	Dr	6¼	305	41			34	2	D	
–3	Richard Martz	Kohl Bros.	12–16–59	470	Dr	5⅝	125	50	sh		46	5	D	
016–646–1	John Calamia	do.	12–14–60	530	Dr	5⅝	99	43	sh		23	18	D	
–2	James Crummel	do.	10–17–61	500	Dr	5⅝	137	62	sh		20	8	D	Dd. 60 ft.
–3	E. A. Knapp	do.	8–28–57	500	Dr	5⅝	111	24	sh		27	15	D	Dd. 23 ft.
–4	Milton Shatto	do.	7– 2–62	485	Dr	5⅝	100	48	sh		15	12	D	
–5	Chester Snavely	do.	4–13–62	495	Dr	6¼	102	48			30	30	D	
016–647–1	Guy E. Miller	do.		485	Dr	6					6	30	D	
016–649–1	J. H. Troup	do.		445	Dr	6¼	92	38	sh		30	15	D	
016–651–1	Robert L. Chambers	do.	4–25–59	440	Dr	5⅝	125	24	sh		45	20	D	
–2	East Harrisburg Cemetery Co.	do.	5– 8–59	460	Dr	5⅝	110	27			0	30	Irr	Dd. 37 ft.
–3	Roosevelt Fowler	do.	5–13–64	460	Dr	5⅝	91	39	sh		25	10	D	
017–641–1	Lester A. Schildt Jr.	do.	5–11–61	350	Dr	5⅝	138	42	sh		8	10	D	
–2	Francis Kreiser	do.	5–22–63	340	Dr	6¼	73	41	sh		18	20	D	
017–642–1	Larry Peters Contr.	Ralph Myers	2– 9–62	475	Dr	6	198	33		3–22–62	19.05	3	D	
–2	do.	do.	2– 9–62	470	Dr	6	194	28		3–22–62	14.95	2	D	CA
–3	do.	do.	2– 9–62	470	Dr	6	82	40		3–22–62	21.76	8	D	
–4	J. Leonard Dietz	Gerlach & Sons		470	Dr	6				3–22–62	14.21		C	
–5	J. P. Dietz			480	Dr	6	136			5–17–62	21.78	5	A	WLR 5–62 to 6–64
017–643–1	Robert Mader	Kohl Bros.	5– 1–62	405	Dr	6¼	92	39	sh		25	10	D	
–2	John W. Smith	Gerlach & Sons	12– 3–60	445	Dr	6¼	165	33	sh		30	2	D	
–3	Henry Arndt	do.	11– 1–63	520	Dr	6¼	181	46			13	4	D	
017–645–1	Elder F. Ickes	Kohl Bros.	2– 9–58	470	Dr	5⅝	125	30			15	4	D	
017–646–1	Paul Grouo, Contr.	Ralph Myers	6– 3–64	520	Dr	6¼	202	35				2.5	D	
017–647–1	Louis DeFaleo	Kohl Bros.	8– 1–62	465	Dr	6¼	112	34	sh		22	8	D	

017-648-1	Dauphin Consolidated Water Supply Co.	do.		460	Dr	6	225	33		0	40	A	Flowed 8 gpm.
017-649-1	do.	do.	3-27-50	440	Dr	6	278	26		3	39	A	
017-651-1	Francis Domonick	do.	6-30-59	440	Dr	5⅝	67	44	sh	25	24	D	
-2	Edgemont School	do.	11- 2-58	450	Dr	6	200	57	sh	55	12	Ps	Dd. 134 ft. in 24 hrs.
-3	William Williams	do.	5- 9-59	445	Dr	5⅝	85	62	sh	27	10	D	
018-640-1	R. L. Hummer			460	Dr		75				30	D	
018-641-1	Amos Ginrich	Kohl Bros.	6-14-62	500	Dr	5⅝	90	41	sh	30	24	D	
-2	Robert Kohr	do.	8- 9-61	490	Dr	5⅝	135	60	sh	25	24	D	
-3	Harry Hershey	do.	3-26-59	490	Dr		135			35	10	D	
-4	Thomas Hetrick	do.	11-18-63	490	Dr	5⅝	79	35	sh	40	30	D	
018-642-1	James Landis	do.	3- 8-61	500	Dr	5⅝	200	57	sh	21	20	D	Dd. 89 ft.
-2	Homer S. Diehl	do.		545	Dr		105			25		D	
018-643-1	Robert Eldridge		about 1940	500	Dr		100			50		D	
018-644-1	Richard W. Decker	Kohl Bros.	5-14-59	425	Dr	5⅝	115	26	sh	20	12	D	
018-645-1	Paul Seiler	do.	5-11-53	410	Dr	5⅝	116	26		30	15	D	
018-646-1	Richard Enders	do.	6-21-60	465	Dr	6¼	106	38	sh	10	15	D	
-2	Robert Shaffner	do.	10-12-62	455	Dr	6¼	92	40	sh	25	9	D	
-3	Carl W. Long	do.	11- 8-62	460	Dr	6¼	194	38		42	5	D	
-4	Stuart Feezer	Gerlach & Sons	12- 3-63	440	Dr	6⅝	207	42	sh	15	4	D	
018-647-1	John Hepschmidt, Contr.	Kohl Bros.	3-16-60	500	Dr	6¼	156	83	ss	17	4	D	Dd. 139 ft.
-2	Gilbert R. Minismith, Contr.	do.	4-18-61	515	Dr	5⅝	112	38	sh	12	24	D	
-3	John Hepschmidt, Contr.	do.	6- 6-59	475	Dr	5⅝	91	31	ss	7	8	D	
-4	do.	do.	6- 8-59	470	Dr	5⅝	87	40	ss	7	12	D	
-5	do.	do.	6-30-59	475	Dr	5⅝	71	39	ss	19	14	D	
-6	Earl Hoffman	do.	8-29-60	420	Dr	6¼	70	37	sh	30	20	D	
-7	G. D. Reece	do.	4-10-61	440	Dr	5⅝	136	54	sh	14	6	D	
-8	Raymond E. Noggle	do.	12-13-62	505	Dr	6¼	133	41	ss	32	6	D	
-9	Essis & Sons	Gerlach & Sons	4-24-62	500	Dr	6¼	118	42		15	12	D	
-10	Kenneth Bretz, Contr.	Kohl Bros.	4-15-60	440	Dr	6¼	125	39	sh	30	15	D	
018-648-1	Dauphin Consolidated Water Supply Co.	do.	1959	460	Dr	6	200	47		22	50	Ps.	CA, Dd. 170 ft. in 24 hrs.
018-649-1	Stanley Kuhn	do.	5- 4-60		Dr	6¼	106	51	ss	19	24	D	
018-650-1	I. A. Sleighter		7- 6-60	450	Dr	6¼	237	57		35		D	
-2	Richard Meck	Kohl Bos.		400	Dr	6¼	202	19		45		D	
018-651-1	M. K. Burtrum	do.	5-16-59	390	Dr	5⅝	73	52		40	10	D	
-2	Paxton Methodist Church	do.	12-21-57	380	Dr	5⅝	132	53		38	9	D	
018-652-1	Harry Hammaker	do.	2-17-60	330	Dr	6¼	160	38		27	24	D	Dd. 63 ft.
-2	Ed. Bates Jr.	do.	10-18-62	360	Dr	5⅝	101	53		60	20	D	
019-637-1	R. A. Walborn			360	Dr	6	120			4		D	CA
019-638-1	W. H. Boyer		1964	445	Dr		87					D	
019-639-1	Bert Umberger		1957	400	Dr		91			6	25	D	
-2	John F. Schell	Gerlach & Sons	1961	425	Dr		94				25	D	
-3	Pa. State Farm Bureau	do.	1955	380	Dr		110			19		A	
019-640-1	Ralph Weaver	Kohl Bros.	about 1935	420	Dr		60			10		D	
019-641-1	Robert Cline	Gerlach & Sons	7-10-63	495	Dr	6¼	137	40	sh	25	4	D	
-2	John Reese	Kohl Bros.	5- 8-61	400	Dr	5⅝	135	74	sh	27	15	D	
019-642-1	Martin Holz	do.	1-26-61	490	Dr	6¼	100	37		35	10	D	
019-643-1	Kenneth Engle	do.	5-25-60	540	Dr	6¼	100	31	ss	50	14	D	
-2	Guy J. Rupert	do.	10-29-58	510	Dr	5⅝	110	35	ss	37	10	D	
-3	E. W. Deavon	do.	1958	480	Dr		102					D	
019-644-1	Holy Cross Cemetery	Gerlach & Sons	1964	480	Dr	6⅜	223	43	sh	11	6	D	
019-646-1	Paxtonia Elem. School	Kohl Bros.	4-26-56	510	Dr	8	200	23		25	10	Ps	CA, Dd. 171 ft. in 4 hrs.
-2	Daniel Koch	do.	11- 1-57	460	Dr	5⅝	81	43		25	20	D	Dd. 35 ft.

Table 2. Record of wells in the Martinsburg Formation—Continued

Well number	Owner	Driller	Date completed	Altitude above sea level (feet)	Method of construction	Diameter of casing (inches)	Total depth (feet)	Reported depth to bottom of casing (feet)	Aquifer composition	Static water level		Reported yield (gpm)	Use	Remarks
										Date measured	Depth below land surface (feet)			
019–646–3	Charles Evitts	Kohl Bros.	2–18–60	510	Dr	6¼	115	37	sh		40	15	D	
–5	W. C. Bucher	C. H. Eichelberger	3–26–63	490	Dr	6⅝		70	ss				D	
–6	Lear Siegler Service	Kohl Bros.	7–21–60	460	Dr		195				10		I	
–6a	do.	do.	10– 7–60	460	Dr	6¼	300	50				6	I	Dd. 240 ft. in 12 hrs.
–7	Harry Ulrich	do.	7–27–62	505	Dr	6¼	112	40	sh+ss		43	15	D	
–8	Paxtonia Sch. Bus Garage	do.		500	Dr		200	60			4	30	S	Dd. 16 ft. in 24 hrs.
019–647–1	Dauphin Consolidated Water Supply Co.	do.	7–59	520	Dr	6	300	44			30	75	Ps	CA, Dd. 160 ft. in 24 hrs.
–2	Lower Paxton Twp. Jr. High School	do.		525	Dr		300					25	S	CA, of 2 wells
–3	Larry Gutshall	do.	7– 9–59	525	Dr	5⅝	77	37	sh		37	12	D	
–4	Bernard Kutz	do.	3– 6–59	500	Dr	5⅝	120	36	sh		40	10	D	
–5	A. C. Buch	do.	8–16–57	505	Dr	5⅝	106	47	sh		15	11	D	
–6	Arthur Boyd	do.	5– 1–59	515	Dr	5⅝	110	57	sh		25	20	D	
–7	Glen Glant	do.	5–25–61	515	Dr	5⅝	90	45	sh		15	20	D	
–8	Holy Name of Jesus School	do.		490	Dr	6	200	47.6				60	S	Dd. 165 ft. in 24 hrs.
–9	Frank Nickolson	do.	2– 8–62	480	Dr	5⅝	102	27	ss		20	15	D	
–10	Jacob Stein	do.	8– 3–62	520	Dr	6¼	134	40	sh		41	10	D	
019–648–1	James Feltrow	do.	4–20–59	510	Dr	5⅝	93	31	sh		30	7	D	
–2	Bruce Wyrick	do.	12–26–61	490	Dr	6¼	92	42	sh		30	15	D	
–3	Warren Lynn	do.	11–13–61	480	Dr	6¼	112	49	sh		35	8	D	
–4	Leroy Deardorf	do.	9– 6–61	500	Dr	6¼	91	50	sh		35	20	D	Dd. 55 ft.
–5	Colonial Country Club	do.	7–29–55	485	Dr	6¼	250	22.5			30	25	C	Dd. 59 ft. in 24 hrs.
–6	Mountain View Elem. School	do.	7–10–63	490	Dr	6¼	300	45	ss+sh		50	20	S	
–7	Harold H. Egenreider	do.	11–17–60	490	Dr	5⅝	99	40	sh		18	15	D	ABS
019–649–1	John Riley	do.	7– 3–61	480	Dr	6¼	115	31	sh		25	12	D	
–2	Bernard Juvelier	do.	8–27–59	470	Dr	5⅝	90	26	sh		22	10	D	
–3	Louis Lubrecht	do.	1– 2–57	460	Dr	5⅝	121	42	sh		20	5	D	
–4	Richard Conrad	do.	2–29–60	480	Dr	6¼	162	32	sh		45	6	D	
–6	Presbyterian Church	do.	11–23–60	440	Dr	5⅝	120	47			15	15	D	
–7	W. H. Moore	Gerlach & Sons	10–15–63	400	Dr	6¼	223	64			14		D	
–8	E. W. Forney Jr.	Kohl Bros.	1962	470	Dr	6¼	93	51	sh		47	8	D	
019–650–1	Dauphin Consolidated Water Supply Co.	do.	9– 5–59	480	Dr	5⅝	300	46			27	48	Ps	CA, Dd. 228 ft. in 10 hrs.
–2	Donald Baldwin	do.	7– 9–59	440	Dr	5⅝	79	36			13	24	D	Dd. 13 ft.
–3	Donald Baltosser	do.	7–12–62	480	Dr	6¼	108	37			20	10	D	
–4	Normal Hamill	do.	11–14–60	440	Dr	5⅝	105	47			26	24	D	
–5	E. Barrier	do.	10–10–60	455	Dr	5⅝	160	58			45	10	D	Dd. 65 ft.
–6	B. J. Mescan	do.	6– 8–59	440	Dr	5⅝	100	42	sh		22	10	D	
–7	Chas. W. Wagner Jr.	do.	11– 4–56	440	Dr	5⅝	134	49	sh+ss		23	15	D	
–8	Arthur Frank	do.	4–13–57	475	Dr	5⅝	79	41	sh		20	10	D	

-9	E. R. Seefeldt	do.	8- 1-57	500	Dr	5⅝	94	55	sh		25	12	D	
-10	Herman C. Carver	do.	3-29-57	430	Dr	5⅝	154	84			10	6	A	Dd. 144 ft.
-10a	do.	do.	4- 1-60	430	Dr	6¼	91	30			1	11	D	
019-651-1	J. H. Harro	do.	8-19-57	455	Dr	5⅝	135	35			38	5	D	
-2	Emmett Ulrich	do.	7- 5-63	445	Dr	5⅝	125	45	sh+ss		22	12	D	
-3	Earl Latsha Lumber Co.	do.	5- 5-64	465	Dr	6¼	154	31	sh		38	6	D	
-4	do.	do.	4-27-64	420	Dr	5⅝	114	43	sh		40	7	D	
-5	Blue Ridge Haven	do.	9-17-61	485	Dr	6¼	403	47	sh		33	18	C	Dd. 175 ft.
019-652-1	R. H. Krueger	do.	4-26-62	460	Dr	6¼	150	42	sh+ls	4-27-62	20.83	12	D	CA
-2	Herbert Hoover Elem. School			450	Dr	6	123	118	sh+ls			25	S	CA
-3	C. L. Olson	Kohl Bros.	6- 2-61	400	Dr	6¼	150	43			30	10	D	Dd. 90 ft.
-4	Samuel W. Looker	do.	10-19-59	475	Dr	6¼	132	49			35	20	D	Dd. 10 ft.
-5	Louis Vinicoff	do.	3-28-59	440	Dr	5⅝	105	45	sh		25	10	D	
-6	Joseph Garner	do.	6-26-62	475	Dr	5⅝	146	38			16	24	D	Dd. 60 ft.
019-653-1	Guy Moreno, Jr.	Gerlach & Sons	1963	500	Dr	6¼	137	55	ss+sh		14	8	D	
-2	Walter Liddick	Kohl Bros.	9-20-62	350	Dr	5⅝	99	39	sh		15	5	D	
-3	Stan D. Custer	do.	9-20-62	420	Dr	6¼	133	39	sh		42	12	D	
-4	J. Yale Gordon	do.	1-22-64	365	Dr	6¼	82	54	sh		12	20	D	
-5	Stan D. Custer	do.	6-11-62	410	Dr	6¼	317	43	sh		3	35	D	
020-638-1	Chester Monaghan	do.	10-10-62	465	Dr	6¼	165	25	ss		23	5	D	
020-639-1	D. M. Uhrich	Gerlach & Sons		445	Dr		80	20				15	D	
-2	Albert Lingle, Contr.	do.		460	Dr	6¼	178	44	ss+sh		31	15	D	
-3	Ralph Reese	Kohl Bros. (Myerstown)	9-63	500	Dr		228					12	D	
020-640-1	Ralph Geesaman			435	Dr		30						D	
-2	Francis Mitstifer			430	Dr	6	90				15		D	
020-641-1	Harrisburg Div. Farm Bureau	Gerlach & Sons	12-10-63	415	Dr	6⅝	152	57	ss		80	30	Irr.	
-2	L. R. Lingle			395	Dr	6	78	25			25	9	D	
020-642-1	Herman I. Cassel			490	Dr	6	60			6-29-62	10.60		O	WLR 3-2-62 to 1-2-64
-2	Milford Cassel	Kohl Bros.	11-23-57	440	Dr	5⅝	105	27			18	17	D	CA, U.S. Geological Survey open file report
-3	Blair Claybaugh	do.		505	Dr	5⅝	160	46	sh		40	30	Irr.	Dd. 60 ft.
-4	Ray Hudson	do.	4-24-58	480	Dr	5⅝	157	35	sh		27	3	D	
-5	Don Pankake, Contr.	Gerlach & Sons	3-29-62	445	Dr	6¼	118	66	ss+sh		4	8	D	
-6	do.	do.	3-13-62	485	Dr	6¼	107	41			35	20	D	
-7	David Gaylor	Kohl Bros.	9- 8-61	445	Dr	5⅝	100	54	sh		20	14	D	
020-643-1	W. Hanovr Twp. El. School		1951	500	Dr	8	192	105			25	30	S	CA, Dd. 80 ft.
-2	Elmer T. Bolla	Kohl Bors.	1958	525	Dr	6¼	400	54	sh		30	75	Ps	Dd. 155 ft. in 12 hrs.
-6	Brethren in Christ Church	Gerlach & Sons	1963	510	Dr	6¼	208	43			27	10	D	
-7	Albert M. Balchunes	do.	6-12-62	520	Dr	6¼	212	42	sh+ss		45	2	D	
-8	Steve Gasparevich	Kohl Bros.	5- 4-61	480	Dr	5⅝	98	24	sh		25	12	D	
020-644-1	Mable Ebersole			460	Dr	6	70			6- 8-62	16.72		O	
-2	D. W. Keller	Kohl Bros.	2-22-60	505	Dr	6¼	125	27			30	9	D	
-3	Mt. View Swim Club	do.	1963	485	Dr	6¼	235	37			34	20	C	
-4	Garry O. Johnson	do.	5- 1-62	500	Dr	6¼	215	37	sh		25	3	D	
020-645-1	Chester Megonnell	do.	9-15-41	445	Dr	5⅝	62	21			10	8	D	
-2	John Wysocki	do.	11-25-60	460	Dr	5⅝	95	48			23	10	D	
-3	Karl Raudensky Jr., Contr.	C. H. Eichelberger	1964	415	Dr	6¼	100	36	ss				D	
020-646-1	Masonic Home Board of the Most Worshipful Prince Hall Grand Lodge			490	Du	44	18			6-29-62	9.75		O	CA
-2	Mervin Moyer			505	Dr	6	49			6-29-62	19.42		O	
-3	Wenrich Church			500	Dr	6	46			6-29-62	17.72		O	
-4	St. Thomas Water Co.	Kohl Bros.	11- 3-54	525	Dr	6	260	42			20	24	Ps	CA, Dd. 148 ft. in 24 hrs.

Table 2. Record of wells in the Martinsburg Formation—Continued

Well number	Owner	Driller	Date completed	Altitude above sea level (feet)	Method of construction	Diameter of casing (inches)	Total depth (feet)	Reported depth to bottom of casing (feet)	Aquifer composition	Static water level		Reported yield (gpm)	Use	Remarks
										Date measured	Depth below land surface (feet)			
020-646-5	Linglestown Water Co.	Kohl Bros.	11- 6-53	530	Dr	6	150	43			25	60	Ps	CA, Dd. 59 ft. in 24 hrs.
-6	do.	do.	6-22-55	530	Dr	16¼	152	41			23	25	Ps	CA, Dd. 123 ft. in 24 hrs.
-7	St. Thomas Water Co.	do.	1954	520	Dr	5⅝	233	45		6-29-62	8.14	50	Ps	CA, PT, EL
-8	U.S. Geological Survey	C. H. Eichelberger	6-21-62	500	Dr	6¼	405	24	sh	6-24-62	34.56	65	O	CA, PT, EL, WLR 6-62 to 6-64
-9	do.	do.	6-22-62	500	Dr	6¼	175	44	sh	6-29-62	25.39	30	O	CA, PT, EL, WLR 6-62 to 6-64
-10	do.	do.	6-22-62	500	Dr	6¼	225	23	sh	7-12-62	20.51	7	O	CA, PT, EL, WLR 7-62 to 6-64
-11	St. Thomas Church	Kohl Bros.	5- 8-59	490	Dr	5⅝	116	51			23	12	D	
-12	Guy Runkle	do.	1-16-57	480	Dr	5⅝	140	51			15	11	D	Dd. 125 ft.
-13	Morris Miller	do.	5-27-58	500	Dr	5⅝	117	30	ss+sh		25	5	D	
-14	St. Thomas Church	do.	12-20-62	500	Dr	6¼	73	43	sh		30	12	D	
020-647-1	Linglestown Elem. School	do.	4-14-54	505	Dr	6¼	210	29			4	40	S	CA, Dd. 36 ft. in 24 hrs.
-2	William Meese	do.		510	Dr	5⅝	75	55			21	8	D	ABS
-3	Linglestown Post Offic	C. H. Eichelberger	7-22-61	515	Dr	6¼	115	32			16	8	D	ABS
-4	W. A. Smith	Kohl Bros.		515	Dr	5⅝	181	51			25	12	D	ABS
-5	K. E. Haverstock	do.		500	Dr	5⅝	115	36			28	10	D	
-6	Roland Wary	do.	9- 6-60	505	Dr	6¼	100	30			40	20	D	Dd. 80 ft., ABS
-7	H. W. Jacobs	C. H. Eichelberger	7-20-62	500	Dr	6¼	174	40		8- 6-62	12.55	23	D	PT
-8	Ronald Shearer	Kohl Bros.	2- 3-59	505	Dr	5⅝	88	24	sh		20	7	D	
-9	Dalton Diehl	do.	12-30-59	495	Dr	6¼	78	28	sh		12	10	D	ABS
-10	R. W. Beaver, Contr.	do.	6-23-62	480	Dr	6¼	133	40	sh+ls		20	7	D	ABS
-11	William Horvath			485	Dr	5⅝	130	70	sh+ls				D	ABS
-12	R. W. Beaver, Contr.	Paul S. Grover	8- 2-63	475	Dr	5⅝	80	50	sh+ls				D	
-13	R. A. Jacobs	Kohl Bros.	8-28-53	495	Dr	5⅝	94	33			25	10	D	
-15	Martha Shope	do.	9-18-58	515	Dr	5⅝	123	38	sh		35	30	D	ABS
-16	Ann M. Smith	do.	6-11-57	515	Dr	5⅝	65	35	sh		10	15	D	ABS, Dd. 15 ft.
-17	Raymond T. Stoud	do.	8- 7-57	515	Dr	5⅝	100	50	sh		18	15	D	ABS, Dd. 12 ft.
-18	John Simmons	do.	8-13-57	515	Dr	5⅝	95	28	sh		25	10	D	ABS
-19	Elisebeth Mixell	do.	7-26-62	510	Dr	5⅝	200				25	12	D	ABS
-20	Swartz Supply Co.	do.	8-25-58	510	Dr	5⅝	102	37	sh		25	11	C	ABS
-21	Clarence Allen	do.	8-27-57	515	Dr	5⅝	121	47	sh		30	6	D	ABS, Dd. 115 ft.
-22	Laura Buchanan	do.	9-17-41	505	Dr		52	18			19	6	D	ABS
020-648-1	Paul M. Hoffman	do.		470	Dr	5⅝	210	70			16	10	D	
-2	Robert F. Johnson	do.	5- 9-59	480	Dr	5⅝	64	31			10	10	D	
-3	C. C. Robuck	do.	9-27-61	505	Dr	5⅝	123	53			14	24	D	Dd. 66 ft.
-4	C. P. George	do.	10-18-60	520	Dr	5⅝	127	47	sh		20	30	D	

-5	Kenneth Nebinger	do.	7-20-59	495	Dr	5⅝	106	42	sh		24	17	D	
-6	Alton Zeiders, Jr.	do.	5- 9-63	480	Dr	6¼	165	42	sh		20	10	D	
-7	Colonial Country Club	do.	7- 1-55	450	Dr	6¼	173	27			20	60	C	
-8	W. L. Holderman & Son, Contr.	Gerlach & Son	6-16-60	460	Dr	6¼	164	47	sh		10	17	D	
020-649-1	John W. Crum	Kohl Bros.	5- 4-61	430	Dr	5⅝	81	36			10	30	D	Dd. 25 ft.
-2	John Hughes	do.	3-28-60	425	Dr	6¼	87	33			6	20	I	H_2S in water
-3	James Leach	do.	5-23-61	450	Dr	5⅝	116	63			15	10	D	
-4	Ellis Asper	do.	12-13-48	415	Dr	5⅝	70	12			10	12	D	H_2S in water
-5	Elmer Huges	do.	7-18-63	480	Dr	6¼	155	42	sh		32	6	D	
-6	Louis D. Kern	Gerlach & Sons	1963	445	Dr	6¼	107	42			30	18	D	
-7	Chester Weaver	Kohl Bros.	8-27-59	450	Dr	5⅝	157	29	sh		45	14	D	
020-650-1	George Winterling	Gerlach & Sons	8-17-63	505	Dr	6¼	150	40	sh		9	100	Irr	PT, EL
-2	Blue Ridge Country Club	Kohl Bros.	9-13-55	465	Dr	5⅝	122	35			5	195	Irr	Dd. 100 ft.
021-638-1	Roy A. Eshelman	do.	9-26-62	460	Dr	6¼	174	40	sh		28	12	D	
021-639-1	Jacob H. Shope			380	Dr		37	20			10	18	D	
021-640-1	E. Hanover Township Elem. Sch.	Kohl Bros.	7- 4-52	495	Dr	6	130	38			25	50	S	CA, Dd. 75 ft. after 24 hrs.
-2	Russel Heffelfinger	do.	9- 9-58	505	Dr	5⅝	113	35			40	10	D	
-3	Bethel & Mt. Etna Telephone & Telegraph Co.	Gerlach & Sons		480	Dr	6¼	92	52	sh		28	30	I	
-4	Adam J. Walmer	Kohl Bros.	4-18-59	485	Dr	5⅝	92	26	sh		27	6	D	
-5	V.F.W. Post 9639	do.	5-19-60	460	Dr	6¼	81	35	sh		15	15	D	
-6	Joseph Hewitt	do.	9- 8-60	525	Dr	5⅝	320	38	sh		50	10	D	
021-641-1	Maurice E. Peck	do.	3-20-63	470	Dr	4¼	111	63			14	7	D	
021-642-1	Camp Kiwanis	do.	2-21-58	490	Dr	5⅝	94	46	sh		35	15	D	
-2	William Kepler	do.	8-30-57	425	Dr	5⅝	78	28	sh		20	14	D	
-3	Oscar Leese	do.	8-14-62	480	Dr	5⅝	92	36	ss		30	12	D	
-4	Amos Shutt	do.	6-10-63	400	Dr	6¼	151	24	ss		25	15	D	
-5	Nelson Barber	do.	8-23-63	420	Dr	5⅝	91	26	ss		6	3	D	
-6	R. D. Stiteler	do.	8-10-59	490	Dr	5⅝		48	sh		40	20	D	Dd. 25 ft.
021-643-1	James R. Cooley	do.	5- 9-60	500	Dr	5⅝	79	32	sh		19	25	D	
021-645-1	C. C. Book	do.	5-17-60	455	Dr	6¼	69	37	sh		1	36	D	
-2	Marlin E. Baker	Gerlach & Sons	4-21-62	465	Dr	6¼	62	27			16	60	D	
-3	Glen Hockenbroch	Kohl Bros.	9-15-59	490	Dr	5⅝	85	43	sh		5	24	D	Dd. 35 ft.
-4	James Holman	do.	5- 6-63	500	Dr	6¼	143	54	ss		23	8	D	
-5	Chas. Evitts, Contr.	C. H. Eichelberger	4-16-64	455	Dr	6¼	60	43	ls			40	D	
-6	Joseph Hipple, Contr.	Kohl Bros.	4-28-61	450	Dr	5⅝	71	41	sh		0	15	D	
021-646-1	Albert Keister	do.	8-23-57	470	Dr	5⅝	90	37	sh		10	20	D	
-2	U.S. Geological Survey	C. H. Eichelberger	6-12-63	450	Dr	6¼	225	19	sh+ls	7-11-63	7.21	75	O	CA, PT, EL, WLR 7-63 to 6-64
-3	W. M. Smith	Gerlach & Son	7-10-63	560	Dr	6¼	154	48	sh+ch	7-11-63	55.47	13	D	CA, PT, Dd. 41.5 after 1 hr.
-4	A. J. Watson	Kohl Bros.	11-15-62	460	Dr	6¼	72	31	sh		7	20	D	
021-647-1	U.S. Geological Survey	C. H. Eichelberger	6-13-63	495	Dr	6¼	184	21	sh	7-30-63	3.94	29	O	PT, EL, WLR 7-63 to 6-64
-2	do.	do.	6-13-63	520	Dr	6¼	184	16	sh	7-30-63	18.89	41	O	CA, PT, EL, WLR 7-63 to 6-64
-3	Charles Evitts, Contr.	do.	1964	565	Dr	6¼	185	40	sh		18	8	D	
021-648-1	Eugene Hoerner	Kohl Bros.	10-28-54	760	Dr	6¼	129	87	sh		75	15	D	
-2	Charles Evitts, Contr.	C. H. Eichelberger	1964	565	Dr	6¼	145		ss			40	D	
022-638-1	Raymond Maulfair	Gerlach & Sons	1955	510	Dr	5⅝	125				18	30	D	
-2	Arthur Haines		1940	510	Dr		58				21	15	D	
-3	Walter Conrad	Kohl Bros.	1953	525	Dr	5⅝	121				30	5	D	
022-640-1	Texas Eastern Trans. Corp.	do.	10-55	470	Dr	8	128	24	sh		10	45	I	Dd. 25 ft. in 24 hrs.
-2	Paul R. Boyer	Gerlach & Sons	1-22-64	510	Dr	6⅝	182	42	sh		20	6	D	

Table 2. Record of wells in the Martinsburg Formation—Continued

Well number	Owner	Driller	Date completed	Altitude above sea level (feet)	Method of construction	Diameter of casing (inches)	Total depth (feet)	Reported depth to bottom of casing (feet)	Aquifer composition	Static water level		Reported yield (gpm)	Use	Remarks
										Date measured	Depth below land surface (feet)			
022-640-3	L. C. Bryner	Kohl Bros.	8-28-58	500	Dr	5⅝	93	30	sh		45	15	D	Dd. 48 ft.
022-641-2	Harry Millard	do.	9-29-62	520	Dr	6¼	72	24	sh		18	20	D	
022-642-1	Julius Nilson	do.	10-10-61	450	Dr	5⅝	110	40	sh		12	15	D	Dd. 63 ft.
022-643-1	Quentin Hetrick	do.	9- 2-58	520	Dr	5⅝	110	24	ss		30	30	D	Dd. 20 ft.
-2	Paul Hetrick	do.	4- 6-59	540	Dr	5⅝	121	24	sh		30	10	D	
-3	Joseph Hipple, Contr.	C. H. Eichelberger	11-63	480	Dr	6¼	125	39				20	D	
022-645-1	John Suhr	Kohl Bros.	3- 5-62	720	Dr	6¼	112	44	ss+sh		12	8	D	
-2	William L. Wagner	do.	8- 2-63	625	Dr	6¼	91	59	sh		25	5	D	
-3	Richard Warntz	do.	7-26-61	520	Dr	6¼	72	37	sh		15	20	D	
023-638-1	Thomas Donmoyer	Gerlach & Sons	12- 3-63	460	Dr	6¼	118	26	sh		15	30	D	
023-639-1	John S. Rhine			525	Dr		80				11		D	
-2	Wayne Elliott			530	Dr	6¼	102	39			15		D	
023-640-1	John Backenstoes	Gerlach & Sons	1963	510	Dr	6¼	100	36			17	50	D	
-2	Jacob H. Spangler			540	Dr	6	107	55				30	D	
023-641-1	Manada Golf Course	Gerlach & Sons	7-15-60	530	Dr	6¼	122	42				23	D	
023-642-1	Milton Cioban	Kohl Bros.	5- 9-59	490	Dr	5⅝	104	31	sh		15	18	D	
024-639-1	Samuel Asper			490	Dr	6	110	50			15	27	D	CA

Table 3. Chemical analyses of ground water in the Martinsburg Formation

[Concentrations in parts per million]

Well number	Date of collection	Depth of well	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Total manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	ABS	Remarks
																		Calcium magnesium	Non-carbonate				
017–642–2	3–22–62	194	53	5.8	1.2	0.50	34	9.4	2.2	1.0	142	10	1.2	0.1	1.0	0.01	135	124	7	242	7.9	0.01	
018–648–1	5–16–62	300		17	.33	.00	35	8.6	12	.9	155	6.7	7.5	.1	3.5	.00	166	123	0	281	7.6	.01	
018–651–1 Paxton Creek	9–15–63			3.0	.16	.05	45	6.8	12	2.8	156	19	11	.2	4.8		197	141	13	322	7.7		
Do.	10–18–63		57	6.0	.00	.00	47	8.0	10	3.6	171	18	14	.0	1.8		204	151	11	340	7.8		
019–637–1	1–10–63	110	56	21	.23	.25	26	8.5	6.4	1.2	114	14	1.7	.1	.2		138	100	7	232	7.7		
019–646–1	5–15–62	200		15	.00	.03	59	21	12	2.0	252	18	20	.0	.2	.00	280	234	27	482	7.3	.01	
019–647–1	5–15–62	300		19	.06	.00	39	8.8	8.7	.8	157	4.0	5.4	.1	8.0	.07	173	134	5	289	7.1	.01	
–2	5–15–62	300		15	.06	.00	41	12	8.4	1.2	155	13	11	.1	11	.00	204	152	25	329	7.7	.02	
019–650–1	5–16–62	300		15	.07	.02	35	12	10	1.4	167	17	.9	.1	.0	.00	175	137	0	295	7.4	.01	
019–652–1	5–15–62	150		11	1.6	.03	41	13	5.6	2.0	150	27	5.6	.0	11	.00	198	156	33	325	7.5	.03	
–2	5–15–62	123		23	.31	.35	39	7.1	12	.9	149	20	5.0	.1	.0	.00	185	127	5	288	6.9	.01	
020–642–2	3–26–59	105	58	21	.02	.06	40	14	5.0	1.0	151	39	1.2	.2	.5		194	158	4	310	7.6		
020–643–1	5–15–62	192		16	.07	.00	39	7.3	7.3	.6	148	10	4.1	.1	7.5	.11	170	128	6	276	7.4	.01	
020–646–1	5–24–62	18		9.6	.34	.00	17	5.8	4.9	6.0	20	37	9.6	.0	21		136	67	50	198	6.0	.06	
–4	5–15–62	260		15	.05	.09	47	10	8.7	.7	153	18	18	.1	3.0	.00	211	159	33	347	7.4	.02	
–5	5–15–62	150		14	.00	.15	42	14	14	1.0	170	19	19	.1	.6	.00	213	163	23	371	7.4	.05	
–6	5–15–62	150		14	.00	.15	42	14	14	1.0	170	19	19	.1	.6	.00	213	163	23	371	7.4	.05	
–7	8–16–62	274		18	.00	.01	37	9.0	7.5	.4	155	8.0	3.1	.1	1.8		167	130	3	303	7.3	.03	
020–646–8	5– 6–63	405	55	14	.86	.22	35	15	6.8	1.0	178	10	1.6	.1	1.2		185	149	3	337	7.7	.03	Sample taken at 50 ft.
Do.	5– 6–63	405	55	15	.59	.17	34	15	6.7	1.1	173	10	1.4	.1	.9		172	147	5	327	7.5	.02	Sample taken at 125 ft.
Do.	5– 6–63	405	55	16	.22	.24	34	13	6.8	.9	167	7.6	1.4	.1	1.6		173	139	2	315	7.6	.02	Sample taken at 175 ft.

Table 3. Chemical analyses of ground water in the Martinsburg Formation—Continued

[Concentrations in parts per million]

Do.	8–15–63	405		15	.69	.17	37	12	7.2	.8	181	6.6	1.3	.1	8.4		184	142	0	310	7.4		Sample taken at 250 ft.
Do.	8–15–63	405		18	1.4	.14	36	11	11	.5	179	6.2	1.4	.0	10		180	135	0	294	7.5		Sample taken at 320 ft.
Do.	8–15–63	405		15	.89	.24	37	12	7.2	.8	182	6.2	1.0	.6	8.0		186	142	0	298	7.4		Sample taken at 390 ft.
020–646–9	5– 6–63	175	58	7.4	5.8	.34	14	3.4	4.1	.4	49	16	1.2	.1	.5		76	49	9	127	6.9	.01	Sample taken at 50 ft.
Do.	5– 6–63	175	55	11	4.5	.16	28	6.8	6.1	.4	120	11	1.6	.2	.8		130	98	0	233	7.2	.02	Sample taken at 125 ft.
Do.	5– 6–63	175	55	9.6	1.6	.74	32	8.3	6.7	.4	139	8.8	1.3	.1	.0		150	114	0	257	7.6	.01	Sample taken at 175 ft.
020–646–10	5– 6–63	225	56	11	5.3	.24	42	18	7.1	1.5	210	9.2	1.8	.0	2.2		215	179	7	359	7.2	.03	Sample taken at 50 ft.
Do.	5– 6–63	225	56	13	5.2	.13	35	16	7.1	1.5	186	7.1	1.8	.0	4.7		202	154	1	320	7.4	.03	Sample taken at 100 ft.
Do.	5– 6–63	225	56	14	5.3	.13	35	15	7.1	1.5	180	6.3	1.8	.0	4.4		199	149	2	309	7.5	.04	Sample taken at 150 ft.
Do.	5– 6–63	225	56	13	1.0	.34	36	15	6.8	.8	183	5.7	1.5	.1	2.7		174	152	2	330	7.2	.03	Sample taken at 200 ft.
020–647–1	5–15–62	210		15	.05	.00	57	12	7.3	.7	165	29	18	.1	12	.00	247	192	57	403	7.5	.03	
021–640–1	5–15–62	130		14	.01	.00	68	15	7.3	1.2	201	39	15	.0	24	.00	290	231	67	471	7.4	.04	
021–646–2	9– 5–63	225		13	2.9	.02	30	11	12	.6	164	14	1.7	.2	.7		165	120	0	275	8.2		Sample taken at 60 ft.
Do.	9– 5–63	225		13	2.8	.41	30	14	12	.6	165	13	1.7	.1	.9		166	133	0	286	8.2		Sample taken at 95 ft.
Do.	9– 5–63	225		13	2.1	.40	32	11	13	.8	165	13	1.8	.2	1.3		175	125	0	279	8.0		Sample taken at 160 ft.
021–646–3	7–11–63	154		16	.00	.00	42	12	8.0	.2	187	18	1.4	.2	.8		193	155	2	314	7.6		
024–639–1	1–10–63	110	56	21	.23	.25	26	8.5	6.4	1.2	114	14	1.7	.1	.2		138	100	7	232	7.7	.04	

DEPARTMENT OF INTERNAL AFFAIRS
John K. Tabor, Secretary

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, State Geologist

GEOLOGIC MAP OF THE MARTINSBURG FORMATION IN DAUPHIN COUNTY, PENNSYLVANIA, SHOWING THE LOCATIONS OF WELLS

Geology by L. D. Carswell, J. R. Hollowell and L. B. Platt
Hydrology by L. D. Carswell and J. R. Hollowell

Scale 1:24,000
1 ½ 0 1 2 Miles
1000 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10,000 11,000 12,000 Feet
Contour interval 20 feet
Datum is mean sea level

1968

EXPLANATION

QUATERNARY

Qcl

COLLUVIAL DEPOSITS

Talus debris from the Tuscarora Formation and adjacent Ordovician Formations, consisting mainly of a mixture of quartzite boulders and weathered shale. Ranges from 5 to 50 feet in thickness. Not used as a source of water.

ORDOVICIAN AND SILURIAN

SOr

UNDIFFERENTIATED TUSCARORA AND JUNIATA FORMATIONS

ORDOVICIAN

Lower and Middle Ordovician

Omc

Omb

Oma

MARTINSBURG FORMATION

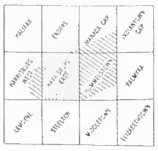
Omc-dark gray shale, siltstone, sandstone and graywacke and red shale with local conglomerates. Red shale is shown by red pattern and graywacke is shown by blue pattern. Yields 1 to 50 gpm. Highest yields are in the sandy units in the northern part of the area.

Omb-variegated red and dark shale, mudstone and chert. Areas of chert shown by X. Yields 5 to 50 gpm

Oma-black shale, limestone and dolomite. Yields 5 to 200 gpm. Highest yields are in the predominantly limestone beds.

Oc

UNDIFFERENTIATED ORDOVICIAN CARBONATES



LOCATION OF MAPPED AREA

▨ Area mapped by L. D. Carswell and J. R. Hollowell

░ Area mapped by L. B. Platt

SYMBOLS

Definite contact

Approximate contact

Inferred contact

Fault, showing relative movement

▲—▲—▲—▲—▲—▲

Thrust fault, dashed where inferred

Strike and dip of beds

Strike and dip of overturned beds

Strike of vertical beds

Strike and dip of cleavage

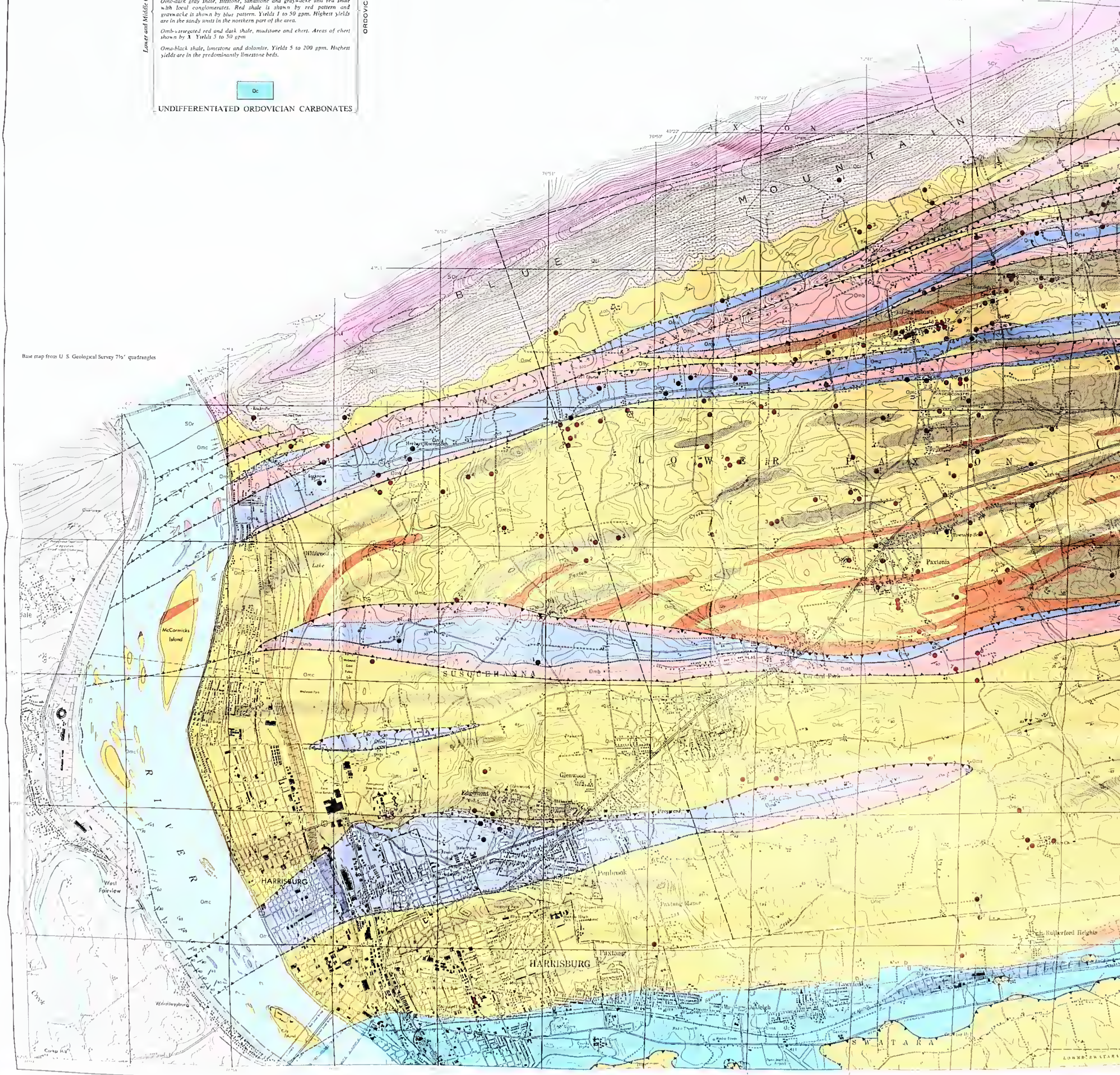
Strike of vertical cleavage

Direction and plunge of lineation and fold axes

Direction and plunge of slickensides

Direction and plunge of minor anticline

Direction and plunge of minor syncline

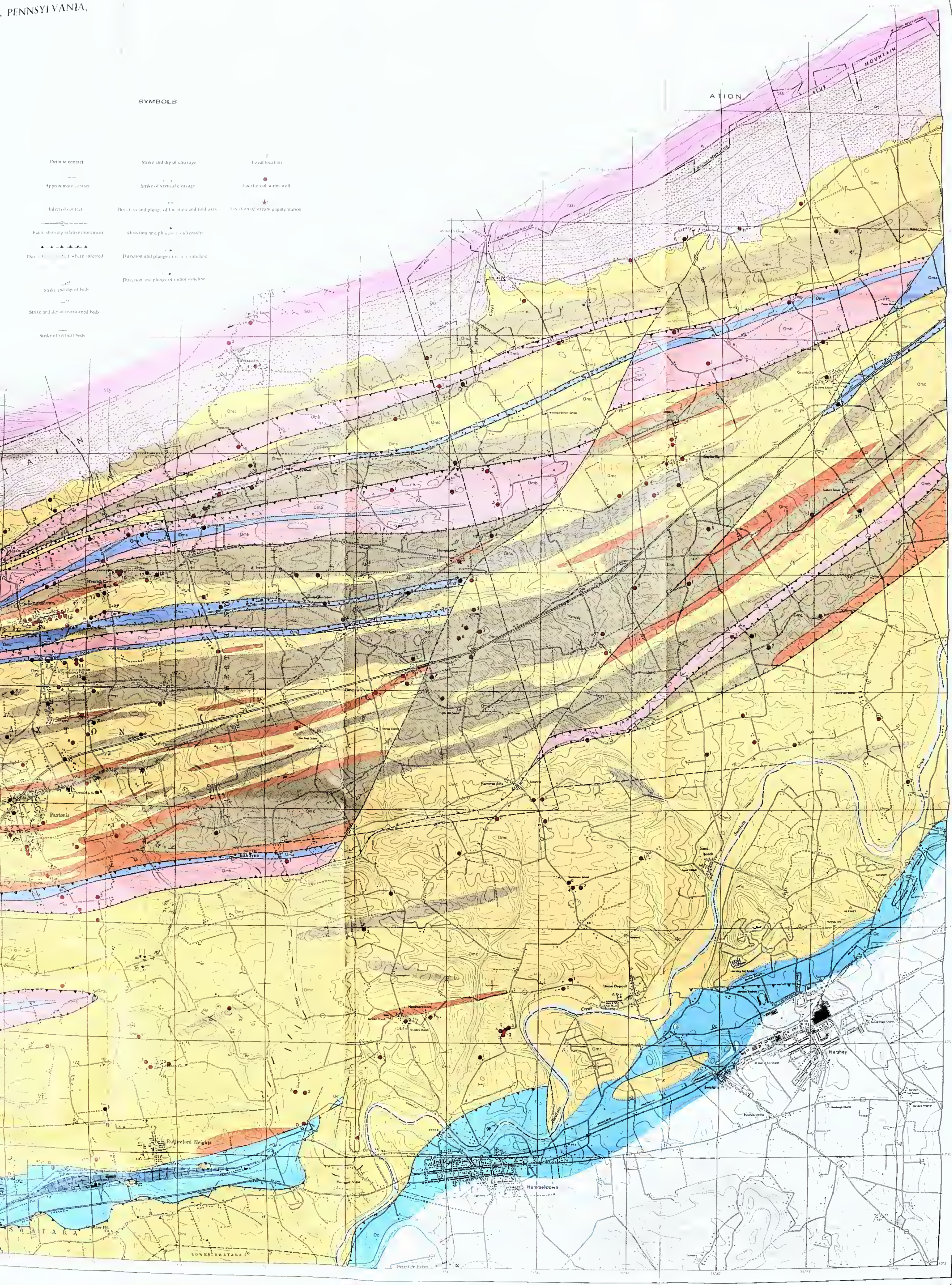


Base map from U. S. Geological Survey 7½' quadrangles

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, State Geologist

BULLETIN W 24, PLATE 1

, PENNSYLVANIA,


SYMBOLS
Definite contact
Approximate contact
Inferred contact
Fault, showing relative movement
Thrust fault, dashed where inferred
Strike and dip of beds
Strike and dip of overturned beds
Strike of vertical beds
Strike and dip of cleavage
Strike of vertical cleavage
Direction and plunge of lineation and fold axes
Direction and plunge of slickensides
Direction and plunge of minor anticline
Direction and plunge of minor syncline
F
Fossil location
Location of water well
Location of stream gaging station
BLUE MOUNTAIN
ATION
A N
A X T O N
WEST
SOUTH HANOVER
S W A T A R A
LOWER SWATARA
Omc
Omb
Oma
Oc
Manada Creek
Swatara Creek
Paxtonia
Rutherford Heights
Union Deposit
Sand Beach
Hershey
Hummelstown